INTERFERENCE EFFECTS DURING BURNING IN AIR
FOR TWO STATIONARY n-HEPTANE DROPLETS

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INTERFERENCE EFFECTS DURING BURNING IN AIR

FOR TWO STATIONARY n-HEPTANE DROPLETS

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ABSTRACT

In order to gain some understanding of droplet interference
during burning, experiments have been conducted for the determin-
ation of the evaporation constant and flame shapes of two closely
spaced n-heptane droplets burning in air. Droplets of approximately
the same and of different diameters were used at various distances
between the droplet centers.

Experimental results on flame shapes and evaporation constants
for closely spaced droplets show somewhat surprising behavior. This
the apparent flame shape changes very little during the burning of
the droplet. The square of the droplet diameter decreases linearly
with time for fixed spacing between droplet centers, at least within
the experimental limits of accuracy. Since geometrically different
conditions are produced continuously during burning, the observed
independence of the slope of plots for the square of droplet diameter
vs time is not obviously expected. Furthermore, for droplets of
different average initial diameters $\bar{D}^o$, the frequency, $\bar{K}'' = \bar{K}'/(\bar{D}^o)^2$,
where $\bar{K}'$ is the usual evaporation constant, is well represented as a
universal function of the initial spacing between droplet centers
$(C^o + \bar{D}^o)$ or adjacent droplet surfaces (C^o).

The evaporation constant, $\bar{K}'$ for constant $\bar{D}^o$, and the frequency
$\bar{K}''$ for arbitrary values of $\bar{D}^o$, increase at first as C^o is reduced
and then decrease again. For large values of C^o, $\bar{K}'$ approaches the
numerical value measured in studies on the burning of single droplets.
This behavior can be understood in terms of a competition between heat
losses to the outside from the flame front surrounding a single drop-
let, which decrease as the droplets are brought together, and oxygen-
deficient atmospheres, which are more likely to occur for very small
values of C^o.

Although an acceptable empirical correlation of experimental
measurements has been obtained, the processes which determine inter-
ference during droplet burning are as yet not understood. In view of
the possible practical importance of interference during burning in
sprays, additional laboratory studies on the burning of simple geo-
metric arrays, other than two droplets, appear to be indicated.

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NOMENCLATURE

a	vertical distance from center of droplet to lower flame surface
b	horizontal distance from center of droplet to outside flame surface
c^o	initial minimum distance between adjacent droplet surfaces
C	minimum distance between adjacent droplet surfaces at time t
D^o	initial droplet diameter
D	droplet diameter at time t
K'	evaporation constant
K''	evaporation frequency
subscript 1	identifies the larger of two droplets
subscript 2	identifies the smaller of two droplets
$\bar{D}^o$	arithmetic average value of D^o for droplets 1 and 2
$\bar{D}$	arithmetic average value of D for droplets 1 and 2
$\bar{K}'$	arithmetic average value of K' for droplets 1 and 2
$\bar{K}''$	arithmetic average value of K'' for droplets 1 and 2
$\bar{D}'$	size constant in Rosin-Rammler distribution law
n	distribution constant in Rosin-Rammler distribution law
w	weight fraction of the spray composed of droplets with diameter larger than D

I. INTRODUCTION

A considerable number of theoretical and experimental papers have been published on the burning of single droplets of fuel (1-5). Experimental studies have been performed on single droplets suspended from fine quartz fibers and burning in an oxidizing atmosphere (5). A reasonable theoretical prediction of mass burning rate for single droplets can be obtained on the assumption that mass transport by diffusion to the flame surface and heat conduction to the burning droplet control the burning rate (4).

Recently an attempt has been made by Graves and Gerstein at the NACA to utilize the results obtained in single droplet studies for the description of burning rates in sprays (6). These authors started with the results of an important theoretical study carried out some years ago by Probert (7). Probert made the following assumptions:

(a) The spray particle size follows the Rosin-Rammler distribution law,

$$w = e^{-(D/\bar{D}')^n},$$ [1]

where w equals the volume fraction or weight fraction of the spray composed of drops with diameters greater than D, $\bar{D}'$ is called the size constant, and n is usually referred to as the distribution constant.

(b) The rate of burning of the droplets is taken to be proportional to the first power of the droplet diameter. In this case it is easily shown that

$$D^2 = (D^o)^2 - K't$$ [2]

where D is the droplet diameter at any time, D^o is the initial diameter, and K'

which has the dimensions of area per
unit time, is known as the evaporation
constant.

Probert has shown how to compute the percentage of unburned
fuel as a function of $\sqrt{K't_r}/D'$ for values of n between 2 and
4, where t_r is the residence time of the burning droplets.
Recently correlations similar to those of Probert have been worked
out for droplet distribution laws other than the Rosin-Rammler dis-
tribution law (8).

Equation [2], which relates droplet diameter to the burning
time, is known to correlate all of the observed results for the
steady burning of single fuel droplets in an oxidizing atmosphere
(4). Therefore, it is of obvious interest to determine whether or
not the value of the evaporation constant, K', for single droplet
theory or experiment has any relation to the value of K' appro-
priate for spray combustion. Graves and Gerstein attempted to
answer this question by measuring the combustion efficiency as a
function of oxygen concentration for a single tubular combustor
using iso-octane as fuel and countercurrent injection. They com-
pared observed combustion efficiencies with calculated combustion
efficiencies using Probert's theoretical analysis in conjunction
with values of K' measured for the burning of single droplets. This
comparison showed that all of the observed results could not be ex-
plained unless spray combustion involves effects, at least for oxygen
concentrations below 24 percent, which can be ignored in the burning
of single droplets. In connection with the use of single droplet
data for studies on spray combustion, it is therefore, of obvious

importance to carry out laboratory studies on interference between droplets during burning.

Although, as a general rule, statistical arrays are more easily interpreted than small numbers of droplets, such as 2, 4, etc., experimental studies on small numbers of droplets may provide a clue for the important physico-chemical processes operative in droplet interference during burning. For this reason experiments have been carried out on the variation of K' with droplet size and droplet spacing for two closely spaced droplets.

II.   EXPERIMENTAL STUDIES ON THE BOILING OF TWO STATIONARY n-HEPTANE DROPLETS

A.   Apparatus

In order to record the flame shape and the decrease in droplet diameter with time, the droplets were suspended on thin quartz fibers which were secured by means of a Sauereisen cement to a metal rod. The rod was bent at an angle of 90 degrees at one end to insure a large supporting surface. The rod was supported on a stand by means of a clamp. Rods of various diameters were used for different minimum spacings between the adjacent surfaces of the droplets, C^o (see Fig. 1). The fibers were enclosed in a circular plastic tube of several inches diameter in order to eliminate ambient air currents. Single droplets of fuel were suspended from the fibers by forcing fuel through a hypodermic needle onto the fiber. The droplet diameters varied from .117 to .259 cms. The droplets were reasonably spherical as shown in the photograph of Fig. 2.

The drops were ignited by using an automobile ignition system connected to electrodes which straddled the two quartz fibers through holes in the tube (see Fig. 3). This method of ignition was found to be useful for values of C^o less than or equal to 0.8 cms. For runs of C^o greater than 0.8 cms, a match was used in order to ignite the droplets.

An electrically driven Arriflex 35mm movie camera was used for photographing the burning droplets. In order to photograph the flame front, a 100 watt bulb was placed behind and off to one side of the burning drops. This method silhouetted the drops and also left the flame front visible as shown in Fig. 2. A ten inch adapter tube and

telephoto lens were employed in order to obtain as large an image
as possible on each frame of film. Kodak Plus X and Kodak Super XX
films were used with apertures of f6 and f9, respectively.

A stroboscope served as timing standard. A ten inch circular
aluminum plate, with three holes placed 120 degrees apart, was
secured to a 75 RPM constant speed motor giving 3.75 flashes per
second. The stroboscope was placed directly behind the burning
drops. The camera speed was adjusted to almost 25 frames per second,
as determined from observations of the stroboscope.

A 3/32 inch ball bearing was photographed at the beginning of
each 100 foot roll of film used. The image served for calibration
and was obtained under the same focusing conditions as for the burning
droplets.

The film was measured by using a microfilm recorder and a
steel scale graduated in millimeters. Two measurements were made
on each drop per frame, namely, the two perpendicular diameters
inclined 45 degrees to the major and minor axes in the plane of
observation. The mean value of these two readings was recorded as
the "effective diameter" of the droplet. It is easily shown that
if the major and minor axes do not differ greatly, as was the case
in our experiments, then the volume of a sphere with the measured
effective diameter is not greatly different from that of the prolate
spheroid, which actually corresponds to the shape of our droplets.
In most cases measurements were taken from ignition to burn out and
recorded approximately every fifth or sixth frame. The flame shape
parameters a_1, a_2, b_1, and b_2 (see Fig. 1), were also measured.

TABLE I   EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS
BURNING IN STILL AIR

FIGURE	D_1^o, cm	D_2^o, cm	C^o, cm	K_1'	K_2'
4	0.194	0.166	0.020	0.0094	0.0082
5	0.101	0.174	0.114	0.0096	0.0094
6	0.166	0.154	0.103	0.0139	0.0130
7	0.192	0.176	0.230	0.0105	0.0096
8	0.165	0.142	0.264	0.0136	0.0122
9	0.182	0.173	0.752	0.0153	0.0141
9	0.182	0.182	0.392	0.0140	0.0140
10	0.173	0.173	1.125	0.0139	0.0133
10	0.162	0.156	1.47	0.0124	0.0115
11	0.130	0.127	0.222	0.0080	0.0072
11	0.138	0.134	0.208	0.0068	0.0063
12	0.135	0.117	0.313	0.0085	0.0085
12	0.124	0.124	0.235	0.0075	0.0070
13	0.133	0.122	0.580	0.0091	0.0080
13	0.126	0.126	0.40	0.0086	0.0086
14	0.136	0.120	0.496	0.0091	0.0068
14	0.121	0.113	0.384	0.0074	0.0074
15	0.143	0.142	0.533	0.0110	0.0110
16	0.141	0.135	0.538	0.0097	0.0093
16	0.155	0.142	0.496	0.0122	0.0114
17	0.156	0.147	0.813	0.0123	0.0113
17	0.156	0.141	0.43	0.0110	0.0112
17	0.156	0.156	1.10	0.0107	0.0108
18	0.208	0.155	0.126	0.0107	0.0104
19	0.209	0.170	0.352	0.0123	0.0109
20	0.195	0.148	0.375	0.0088	0.0089
21	0.167	0.115	0.520	0.0150	0.0090
22	0.160	0.131	0.532	0.0140	0.0150
23	0.192	0.148	0.026	–	0.0068
24	0.203	0.164	0.150	–	0.0124
25	0.191	0.178	0.246	0.0157	–
26	0.152	0.113	0.355	–	–
27	0.202	0.179	0.362	–	–
28	0.200	0.156	0.466	0.0133	–

III. EVAPORATION CONSTANTS AND EVAPORATION FREQUENCIES FOR TWO
STATIONARY n-HEPTANE DROPLETS BURNING IN CLOSE PROXIMITY

A. Evaporation Constants

If the evaporation constant, K', of a stationary fuel droplet
suspended from a quartz fiber is modified extensively by the presence
of a second droplet burning in close proximity, then one would expect
the value of K' to depend both on the instantaneous values of the
droplet diameters and on the distance between the droplets. In other
words, one might expect K' to be a function of the time. Contrary
to this idea, it has been found that K' is constant, within the
experimental limits of accuracy, for two droplets of n-heptane
burning in close proximity. In fact, as will be shown in greater
detail presently, the observed values of K' seem to depend only
on the initial droplet diameters and on the initial spacing between
the droplets burning in air.

The observed values of $\overline{K}' = (1/2) (K'_1 + K'_2)$ for droplets in
which D_1^O and D_2^O did not differ by more than 20% are plotted as a
function of C^O in Fig. 29. Reference to Fig. 29 shows that the ex-
perimental results fall roughly into two categories depending on the
initial average droplet diameter $\overline{D}^O = (1/2) (D_1^O + D_2^O)$. The numbers in
Fig. 29 correspond to the numbers of the figures in which the raw data
of D_1^2 vs t and of D_2^2 vs t are shown (Figs. 4 to 17). Reference to
Fig. 29 shows that the average evaporation constant increases when
C^O is reduced from larger values with negligible droplet interference,
presumably because heat losses from the flame surface are reduced
by the proximity of a second heat source for sufficiently small
values of C^O; $\overline{K}'$ reaches a maximum and then decreases again

as C^o is made still smaller. A decrease in $\overline{K}'$ for very small
values of C^o could be produced through the creation of oxygen-
deficient atmospheres resulting from increased competition for the
oxygen supply furnished by convection and diffusion. On the basis
of the proposed picture the maximum in plots of $\overline{K}'$ vs C^o results
through a balance between two opposing factors, viz., decreased heat
loss and decreased oxygen supply. The proposed interpretation, if
applicable to spray combustion, may be of considerable practical
importance.

A number of attempts were made to relate $\overline{K}'$ with simple functions
of C^o, $C^o/\overline{D}^o$, $C^o + \overline{D}^o$, $(C^o + \overline{D}^o)/\overline{D}^o$, etc., in order to reduce
the scatter of experimental points for different values of $\overline{D}^o$. These
efforts were, however, unsuccessful and suggest that the evaporation
constant, K', which is independent of initial droplet diameter in
single droplet studies, loses its significance as a basic correlating
parameter for two droplets burning in close proximity. Whether or
not this conclusion applies to sprays cannot be said without further
experimental work. In the meantime, however, it appears that, without
further proof, applicability of the droplet burning relation $D^2 = (D^o)^2 -$
$K't$, used in Probert's analysis, is subject to some question. The fact
that $\overline{K}'$ varies with $\overline{D}^o$ is shown more directly by plotting $\overline{K}'$ as
a function of $\overline{D}^o$ for a group of experimental data with nearly equal
values of C^o.

Two burning droplets meet the requirements of geometric
similarity when they have the same values of C/D and of $\overline{D}$. It

is easily shown from plots of $C/\bar{D}$ vs $\bar{D}$ that (nearly) inter-
secting curves are characterized by greatly different values of
$\bar{K}'$ if the values of $\bar{D}^O$ are different. In other words, the value
of the evaporation constant is determined primarily by the initial
conditions and, if at all, only to a lesser extent by geometrical
arrangement. It is possible that the initial convection currents,
which depend on the initial conditions, exert a profound influence
on the burning of two adjacent droplets throughout the droplet
life.

B. Evaporation Frequencies

In view of the apparent dependence of $\bar{K}'$ on $\bar{D}^O$, attempts
were made to find a simple function of $\bar{K}'$ and $\bar{D}^O$ which would
depend only on C^O or on a known function of C^O and $\bar{D}^O$. An
obvious choice is the ratio $\bar{K}'' = \bar{K}'/(\bar{D}^O)^2$ to which we shall refer
as the evaporation frequency.

In Figs. 30 to 32 we have plotted $\bar{K}''$ as a function of C^O,
$C^O + \bar{D}^O$, and $C^O/\bar{D}^O$, respectively. Reference to Figs. 30 to 32
shows that a fair correlation of all of the experimental data has
been obtained, the scatter being perhaps smaller in the plots using
C^O and $C^O + \bar{D}^O$ as abscissa than in the plot using the dimensionless
quantity $C^O/\bar{D}^O$. In the absence of an adequate theory concerning
droplet interference, the significance of the observed "correlations"
is obscure, as is also any extrapolation to sprays. For this reason
we must content ourselves with the observation that, for two n-heptane
droplets burning in close proximity, the observed values of $\bar{K}'/(\bar{D}^O)^2$

are fairly well represented as a function of either C^o or of $C^o + \overline{D}^o$.
Constancy of the evaporation frequency, except for variations in C^o,
means that one fundamental burning rate law for fixed values of C^o
has the form

$$(\overline{D})^2 = (\overline{D}^o)^2 - \overline{K}^* (\overline{D}^o)^2 \, t \qquad [2]$$

IV. FLAME SHAPES

The flame shapes for two droplets, as for single droplets, are
determined largely by convection currents. A qualitative description
of flame shapes can be given on the basis of available experimental
measurements.

A. Flame Shapes for Single Stationary Fuel Droplets Burning in Air

According to an elaboration* of observations by Kumagai and Kimura
(9), a realistic description can be obtained for the flame shape sur-
rounding a burning single, stationary, droplet of fuel in air by
allowing for the influence of free convection.

A burning fuel droplet in air must produce free convection
currents. In Fig. 33 we show a schematic diagram of the flame
shape for a single droplet. We shall assume that the convection velocity
corresponds to a uniform flow with velocity U at some distance upstream
from the initial undisturbed flame front. The combination of burning
droplet and convective flow then acts as a source in a uniform flow
field and, at steady burning, establishes the flow pattern correspond-
ing to a half body as lower boundary. The stream surface through the

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*The present discussion is based on ideas formulated by L. Lees and
S. S. Penner.

lower stagnation point may be thought of as dividing initially the stream lines originating from the source (fuel droplet) and the streamlines established by convective flow. This situation is, however, unstable and diffusive transport of oxidizer and fuel across the stream surface must be established. The tangential flow velocities at the stream surface of fuel vapor and air are initially equal. Presumably concentration and temperature gradients are established during steady burning in such a way that diffusive transport of fuel and oxygen brings a stoichiometric mixture roughly to the stream surface, thereby making the lower stream surface a flame surface.

Most of the fuel vapor is deflected around the stream surface and ultimately moves vertically upward through a cylinder of diameter b. An air flow is established parallel to the fuel flow, moving with the same uniform velocity U as the approach stream and the fuel vapor. Hence conditions are established for the formation of an overventilated diffusion flame and the flame height h can presumably be calculated, in first approximation, from the classical treatment of Burke and Schumann for diffusion flames.

The preceding remarks may be summarized by noting that the effect of free convection is, in first approximation, a distortion of the spherical flame front to a flame surface whose lower boundary is the stream surface corresponding to a source of strength $\dot{m}_F / \rho_F$ ($\dot{m}_F =$ mass rate of burning of fuel droplet, $\rho_F =$ density of fuel vapor)

in a uniform flow of velocity U; the upper flame surface may be
described as the flame front for a cylindrical diffusion flame with
the inside cylinder of diameter b and the flow velocities of fuel
and air equal to U.

The postulated description of the flame surface leads to results
which are in accord with the observations of Kumagai and Kimura. Thus

$$2 b = \sqrt{2 \dot{m}_F / \rho_F \pi U} \; , \qquad\qquad [4]$$

and

$$2b/a = 2\sqrt{2}. \qquad\qquad [5]$$

Furthermore, since U sin Θ (i.e., the tangential flow velocity
of air at the stream surface) must be equal to the tangential flow
velocity of fuel vapor, one would expect that U and $\dot{m}_F$ are pro-
portional to each other.

Thus
$$U \sim b \qquad\qquad [6]$$

since $\dot{m}_F$ is known to be proportional to the diameter of the burning
fuel droplet. Also b should be a constant for a given fuel drop-
let and oxidizing medium; Kumagai and Kimura (9) found b to remain
unchanged, for example, for octane oil as the droplet diameter was
increased from about 0.07 to 0.12 cm.

The functional form of the relation between $\underline{b}$, $\dot{m}_F$, and U, as given in Equation $[4]$, is in accord both with the picture of a lower flame surface corresponding to the stream surface and also with the following considerations. Most of the energy transport to the fuel droplet occurs from the upper flame surface. The area of this surface (for $h \geq b$) is roughly proportional to bh. But for a cylindrical diffusion flame $h \sim b^2 U$. Hence the flame surface varies as $b^3 U$. The energy transport to the fuel droplet is proportional to the product of flame surface and temperature gradient at the flame surface. The latter quantity would be expected to vary roughly as $1/b$. Finally, the total energy transport to the fuel droplet must be proportional to $\dot{m}_F' \rho_F$. Therefore,

$$b^2 U \sim \dot{m}_F / \rho_F$$

or

$$b \sim \sqrt{\dot{m}_F / \rho_F U} \; .$$

Although the picture of the formation of a heterogeneous diffusion flame given above seems qualitatively correct, it is apparent that a complete solution of the problem under consideration cannot be obtained without a quantitative analysis of energy transport to the droplet from the flame boundaries. However, the qualitative considerations based on the work of Kumagai and Kimura and sketched above suggest that the following important results will be obtained: (a) $\dot{m}_F$ weakly dependent on flame shape; (b) U and $\underline{h}$ proportional to D; (c) $\underline{h}$ proportional to b^2; (d) $\underline{b}$ independent of D.

B. Flame Shapes for Two n-Heptane Droplets Burning in Close Proximity

For two n-heptane droplets burning in close proximity it has

already been noted that a_1, b_1, a_2, and b_2 change very little during droplet burning. Furthermore, reference to Figs. 4 to 8, Fig. 15 and Figs. 19 to 28 shows that the ratio of b to a is not sensibly different from unity and does not seem to depend strongly on c^0. In some cases, the distances of the flame surfaces from the droplet surfaces remained constant during burning (see Fig. 2).

The droplet spacing parameter C is, of course, determined through the geometric arrangement. Thus

$$C = C^0 + (1/2)(D_1^C - D_1) + (1/2)(D_2^0 - D_2)$$

or

$$C = C^0 + (1/2)D_1^0 \left[1 - \sqrt{K_1 t/(D_1^0)^2} \right] + (1/2)D_2^0 \left[1 - \sqrt{K_2 t/(D_2^0)^2} \right]. \quad [7]$$

Needless to say, the time dependence of C is well represented by Equation [7], as shown in Fig. 34.

V. CONCLUSIONS

The investigations of droplet interference during burning described in this report have shown a number of unexpected results which may well be of importance for a fundamental understanding of spray combustion. In particular, the fact that the evaporation constant is no longer independent of droplet diameter for fixed spacing requires further study. An obvious extension of the present experimental program leads to burning rate studies on simple geometric arrays, such as five droplets. It is also apparent that some fundamental theoretical studies on interference during burning are required.

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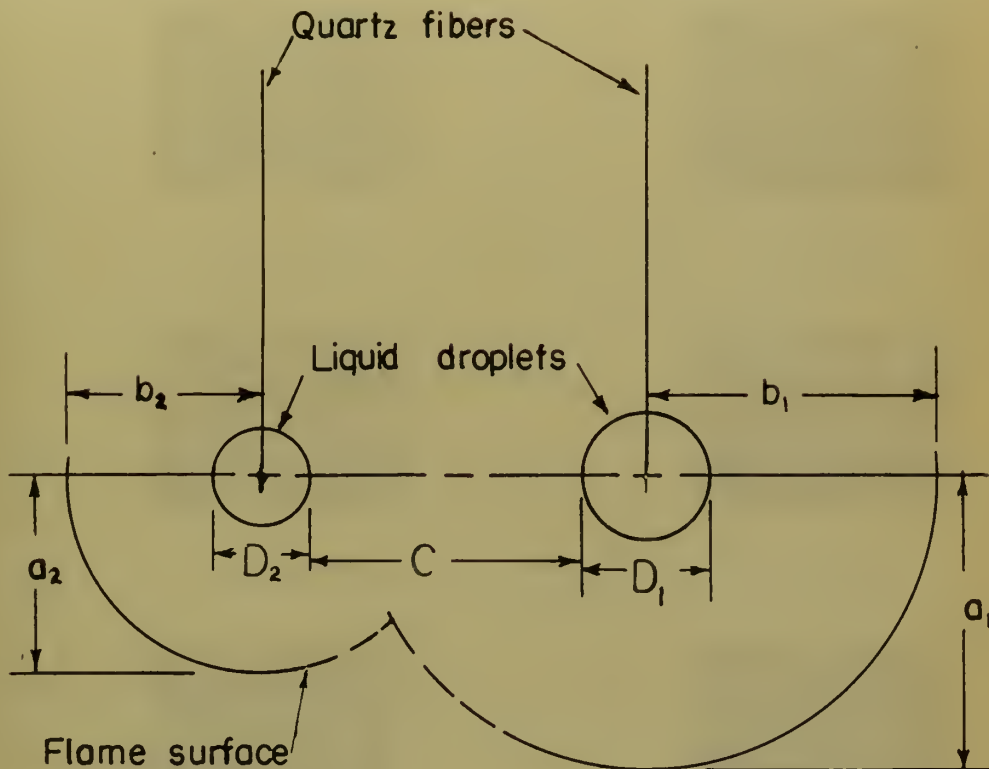
FIGURE I. SCHEMATIC ARRANGEMENT OF FLAME
INTERFERENCE EXPERIMENT WITH TWO DROPLETS
BURNING IN CLOSE PROXIMITY

IGNITION

T=1.44 SEC.
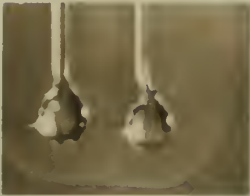
T=0.53 SEC.

T=1.70 SEC.

T=0.75 SEC.

T=1.90 SEC.

T=0.92 SEC.

T=2.15 SEC.

T=1.28 SEC.

T=2.40 SEC.

FIGURE 2.   PHOTOGRAPH OF TWO n-HEPTANE DROPLETS BURNING IN AIR (D_1^o = 0.181cm, D_2^o = 0.174cm, C^o = 0.114cm)
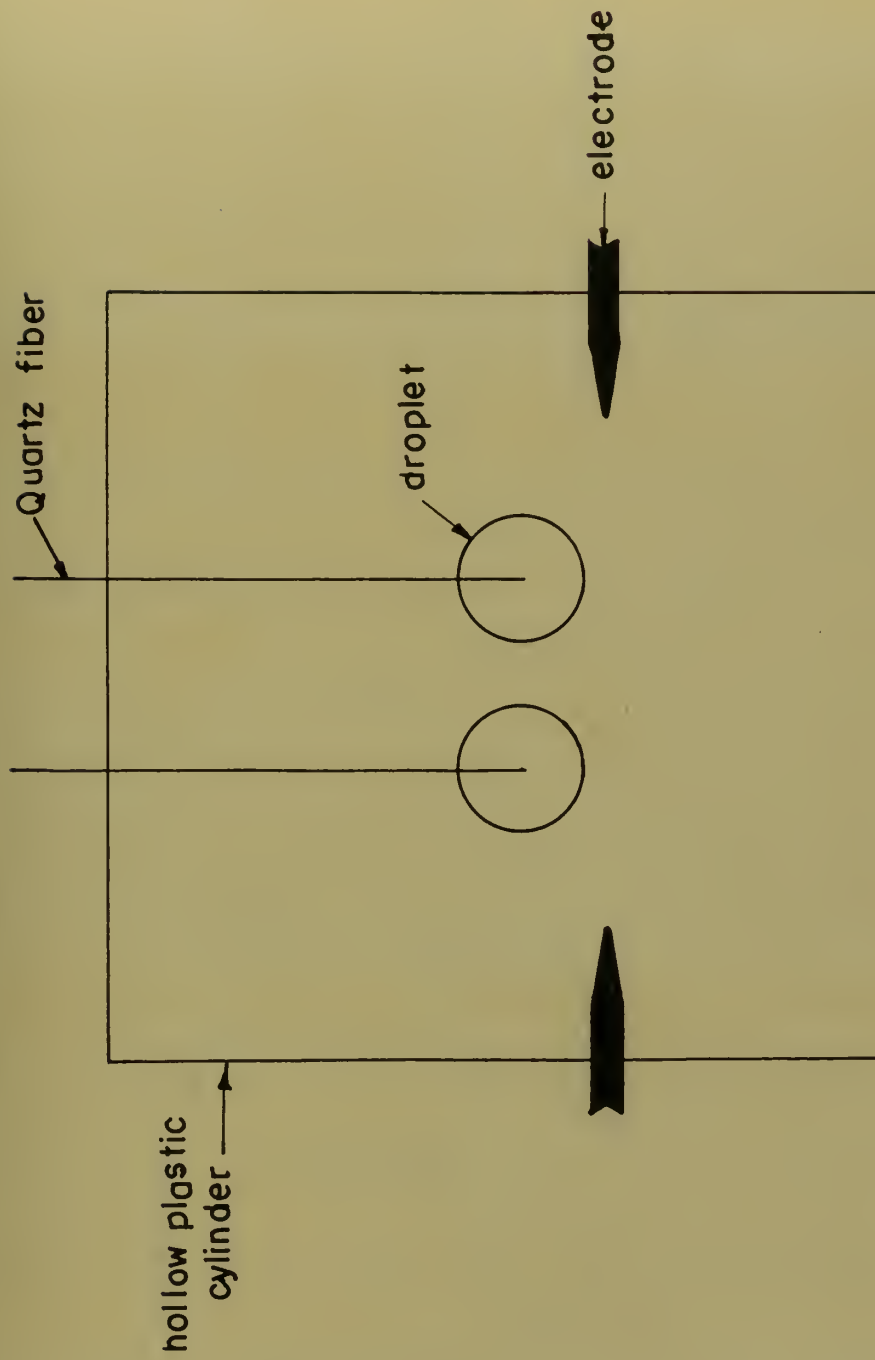
FIGURE 3. SCHEMATIC DIAGRAM OF DROPLET
IGNITION
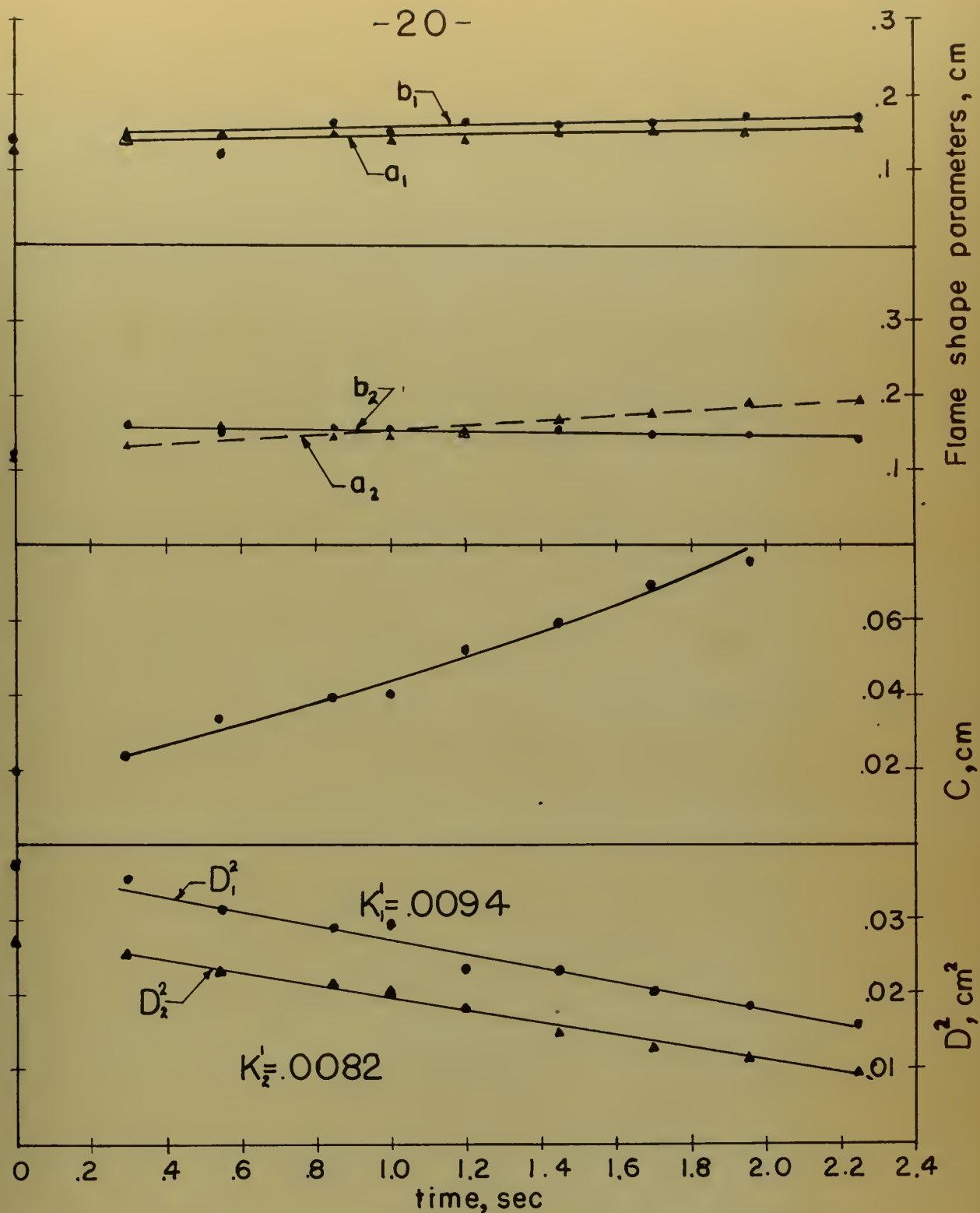
FIGURE 4. EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR (D_1^o=0.194 cm, D_2^o=0.166cm, C^o=0.020cm)
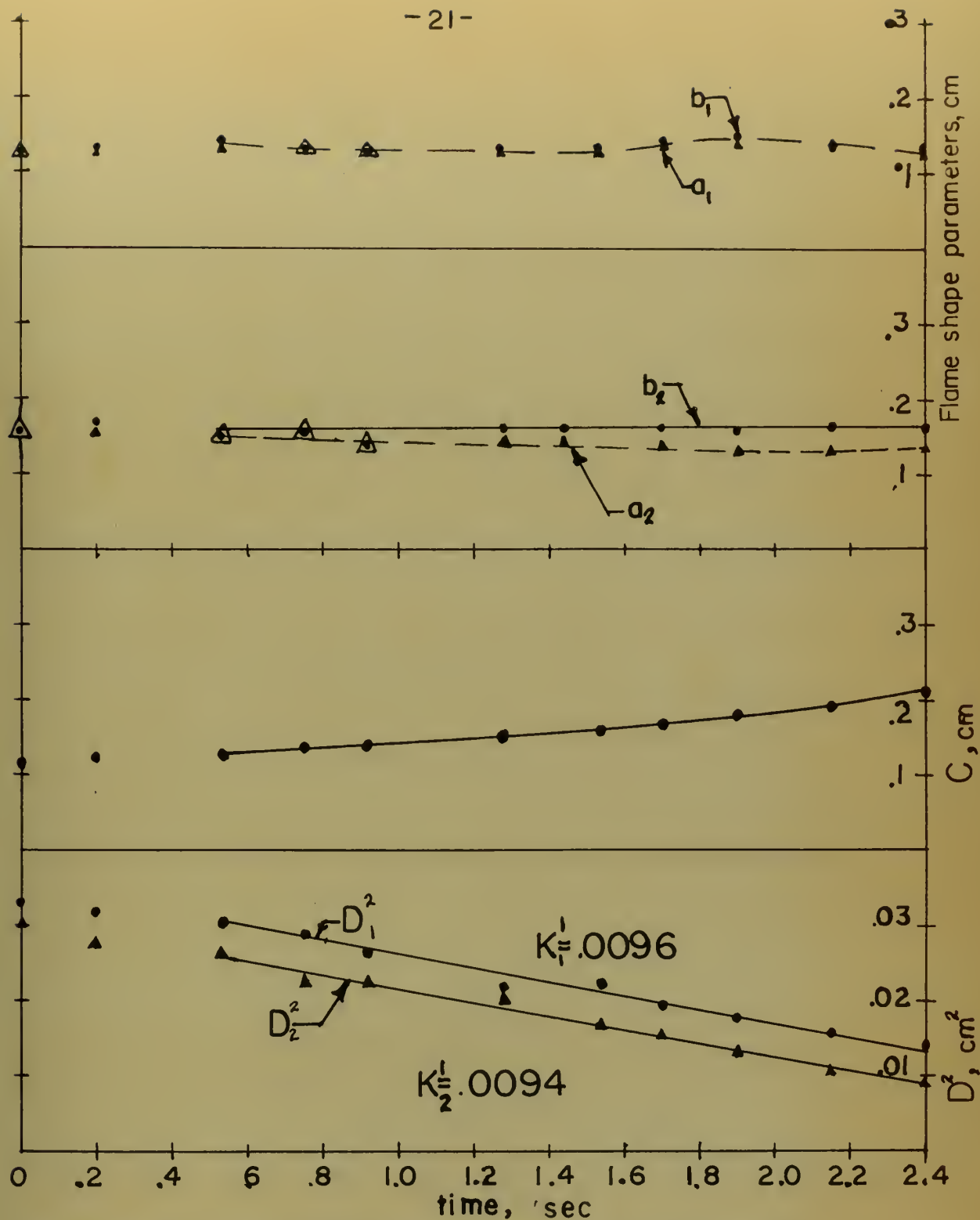
FIGURE 5. EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR (D_1^o=0.181cm, D_2^o=0.174cm, C^o=0.114 cm)
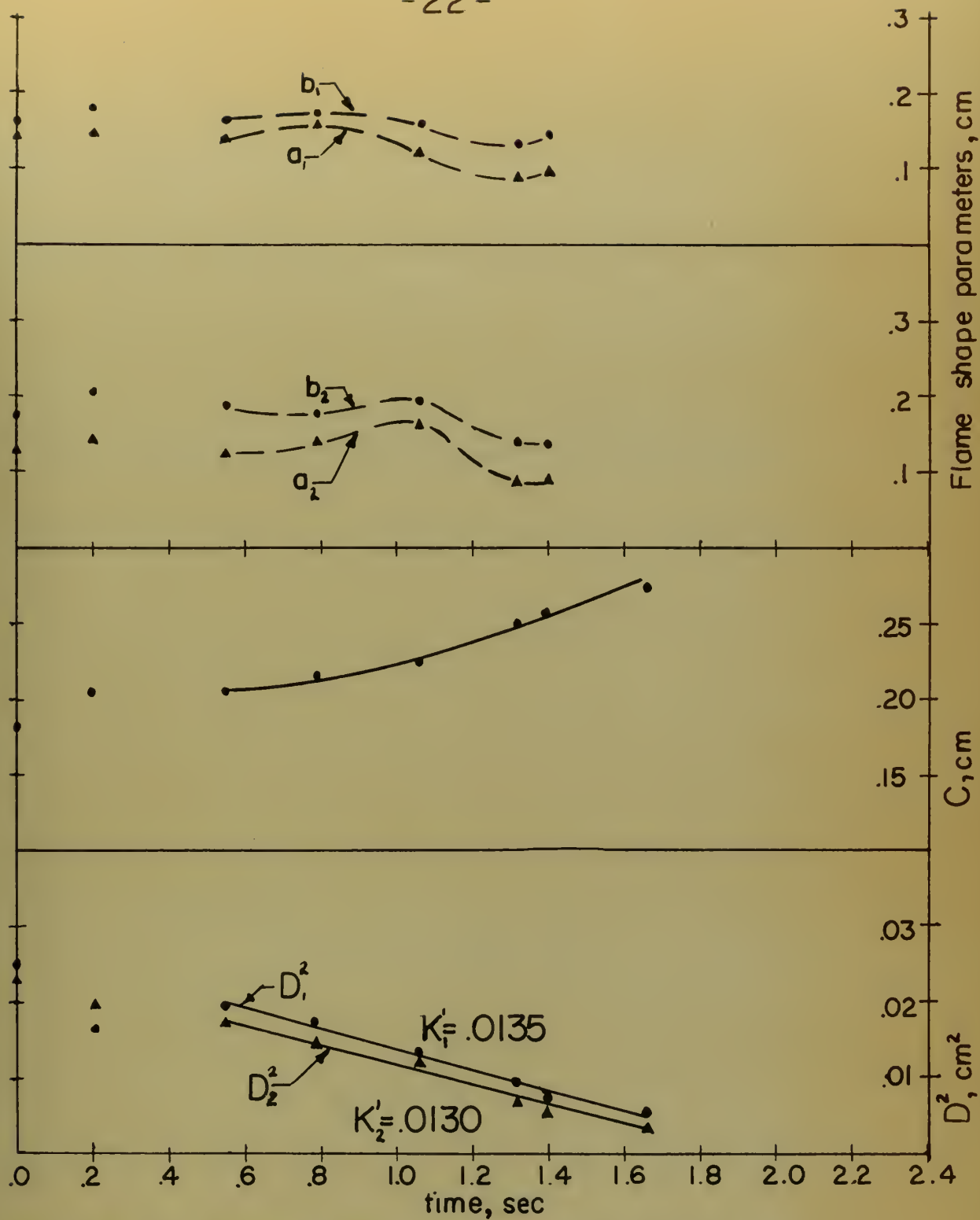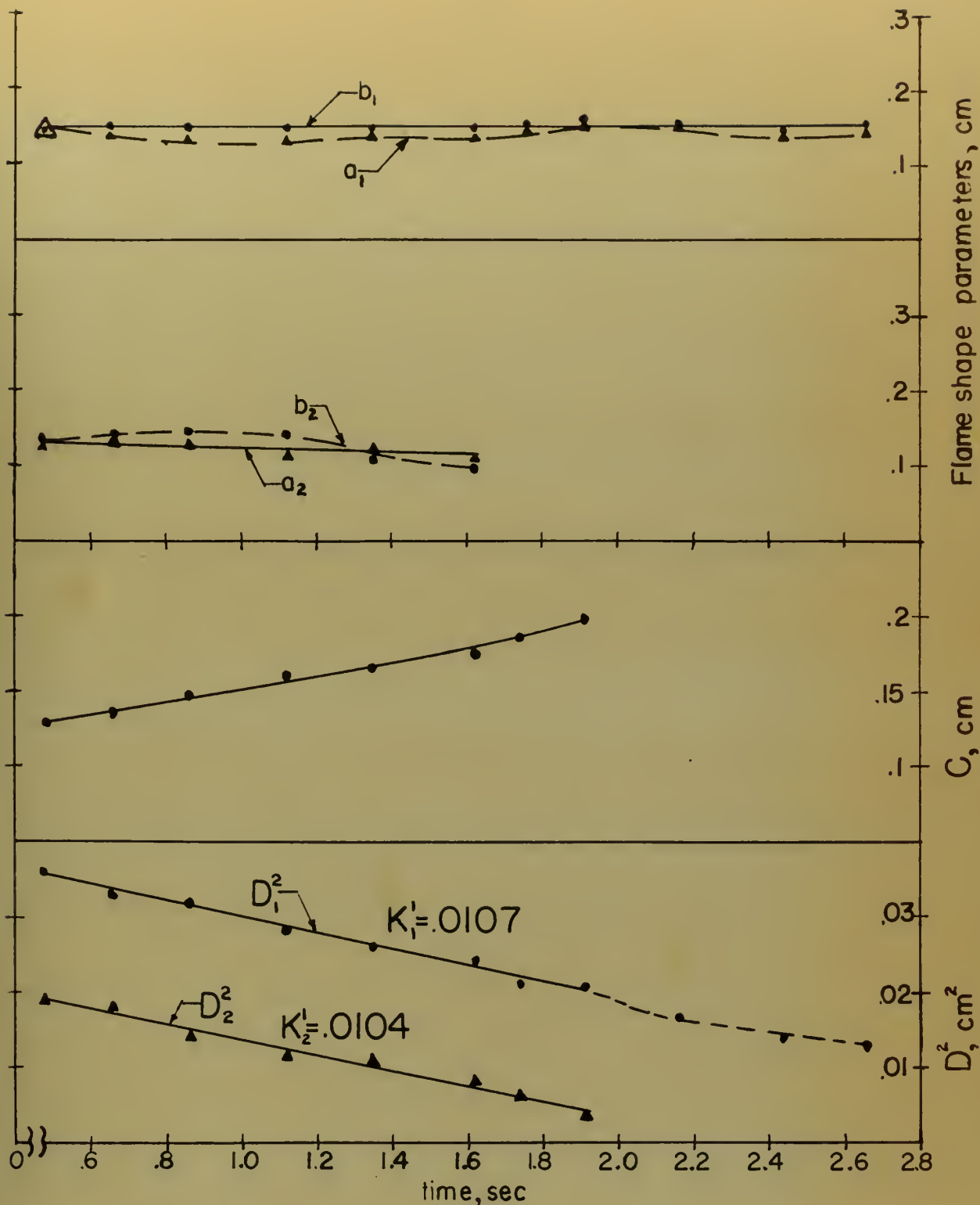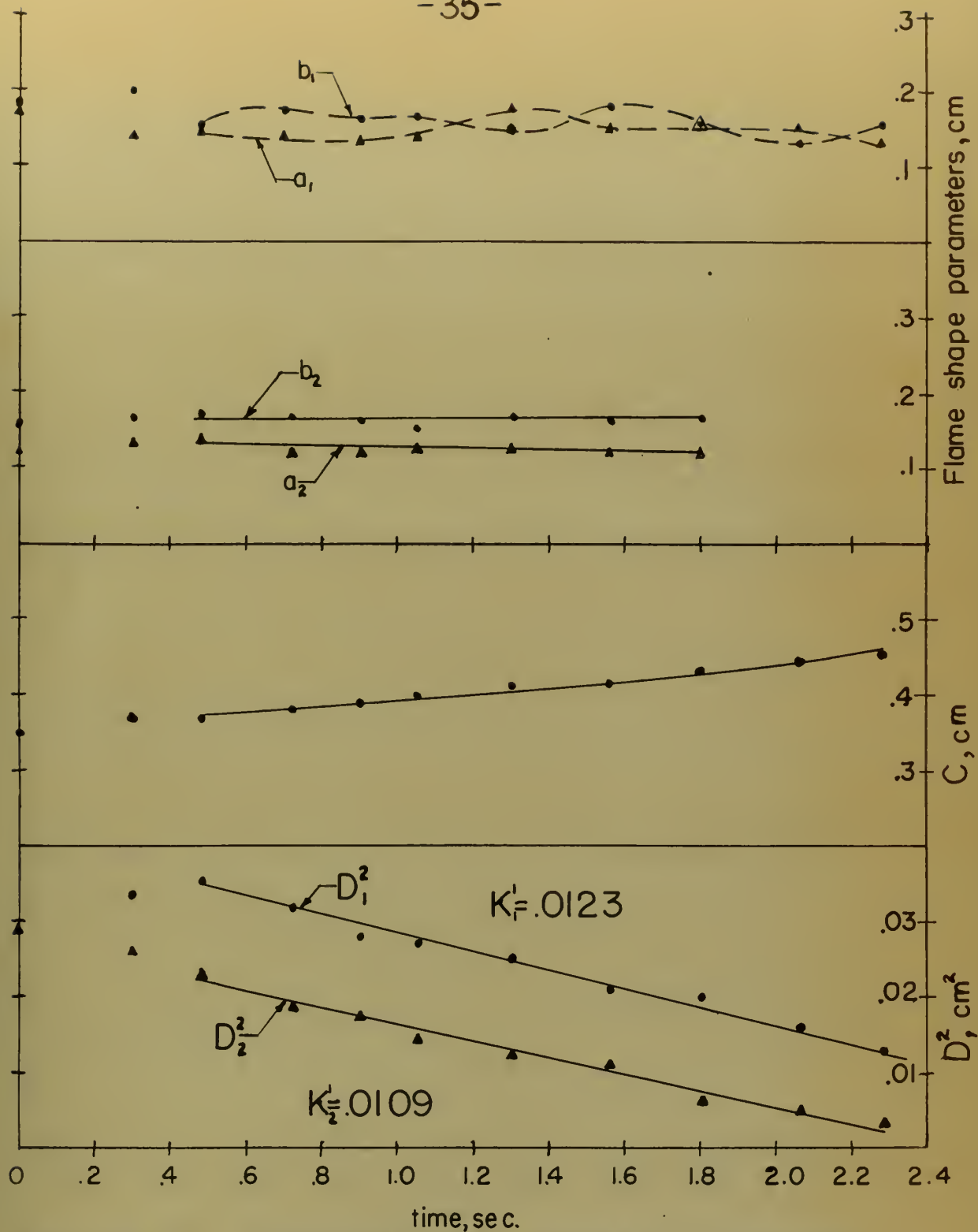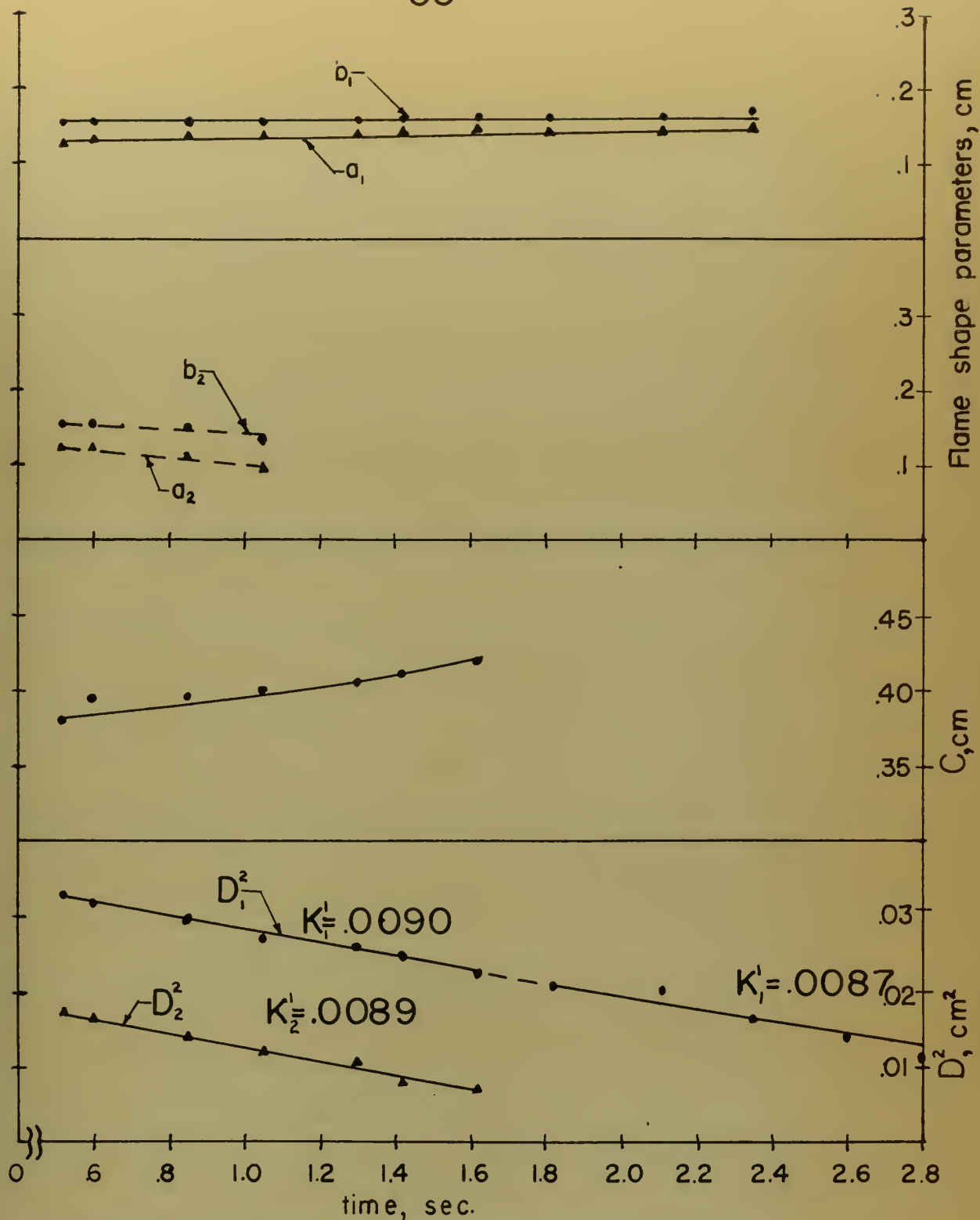
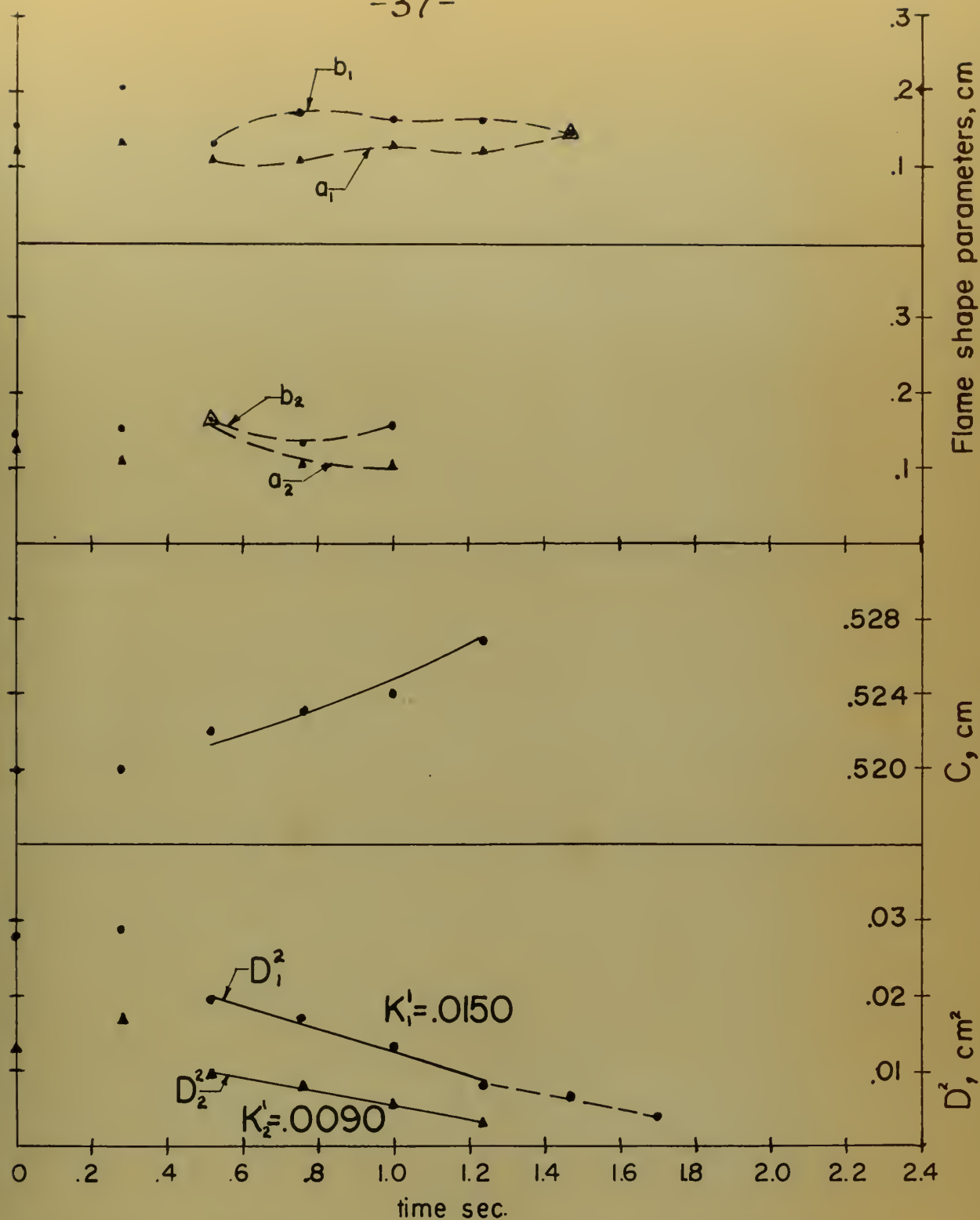FIGURE 6. EXPERIMENTAL RESULTS FOR TWO n - HEPTANE DROPLETS BURNING IN STILL AIR ($D_1^0 = 0.166$ cm, $D_2^0 = 0.154$ cm, $C^0 = 0.183$ cm)
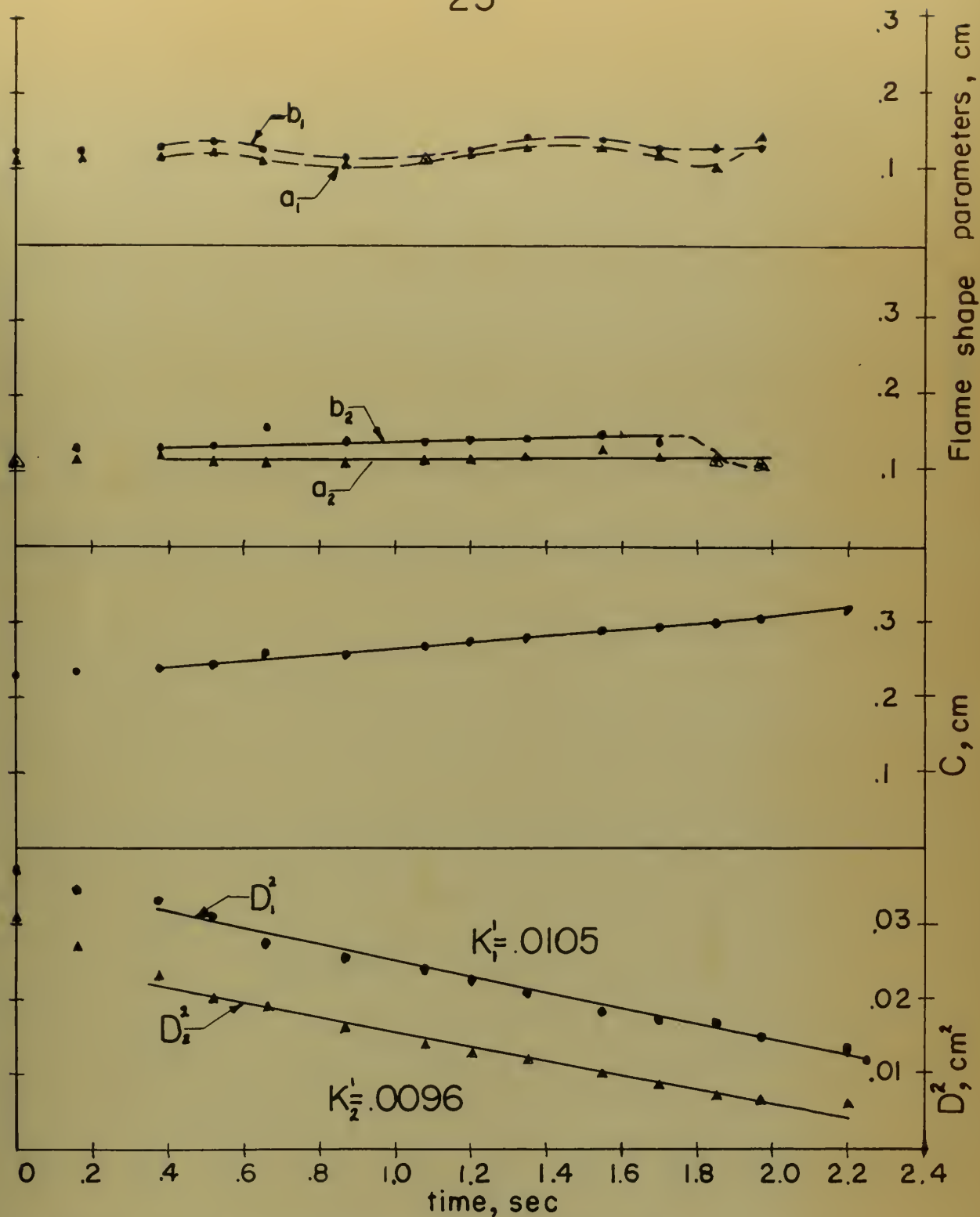
FIGURE 7. EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR (D_1^o=0.192 cm, D_2^o=0.176cm, C^o=0.230 cm)
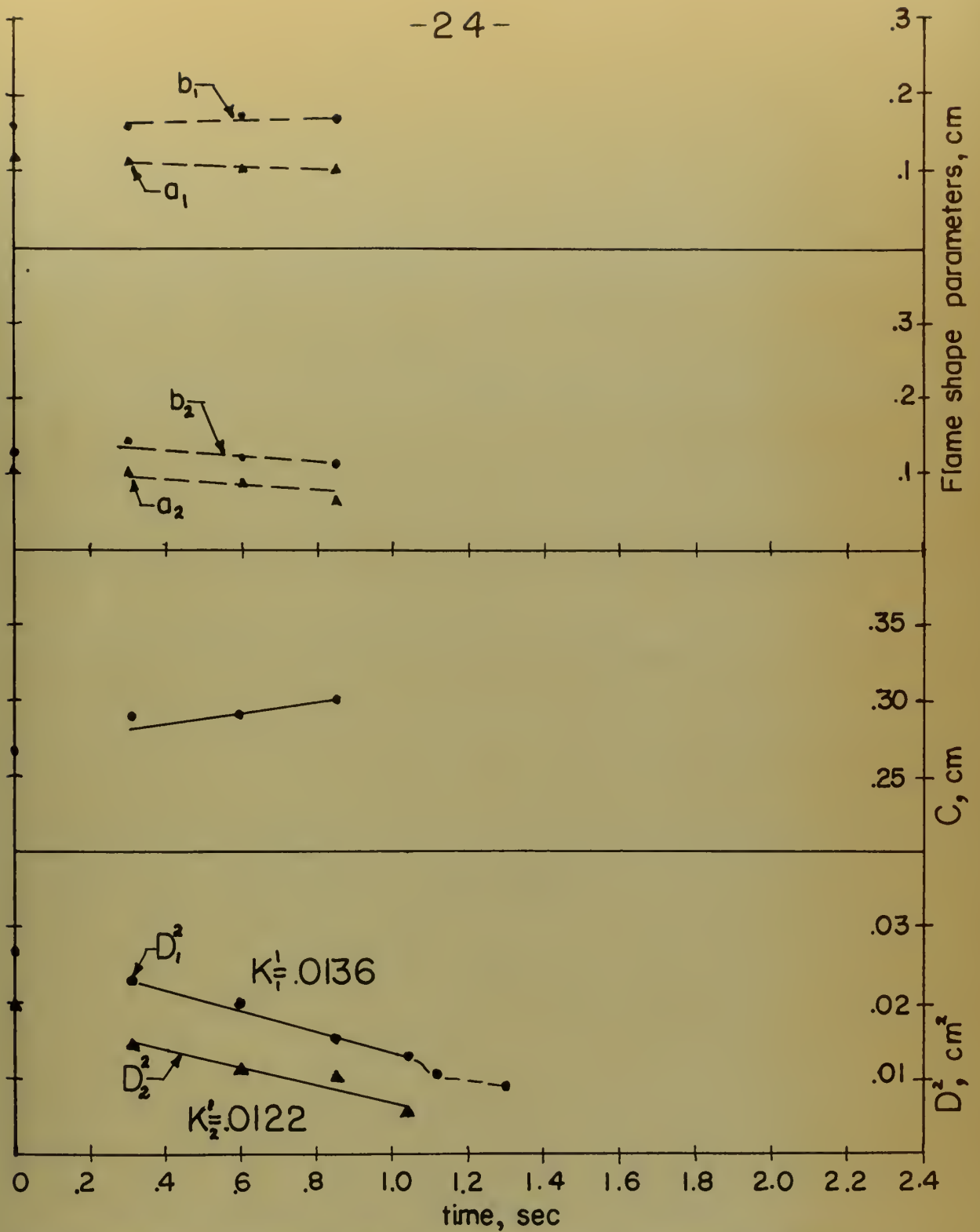
FIGURE 8. EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR (D_1^o=0.165 cm, D_2^o=0.142cm, C^o=0.264cm)
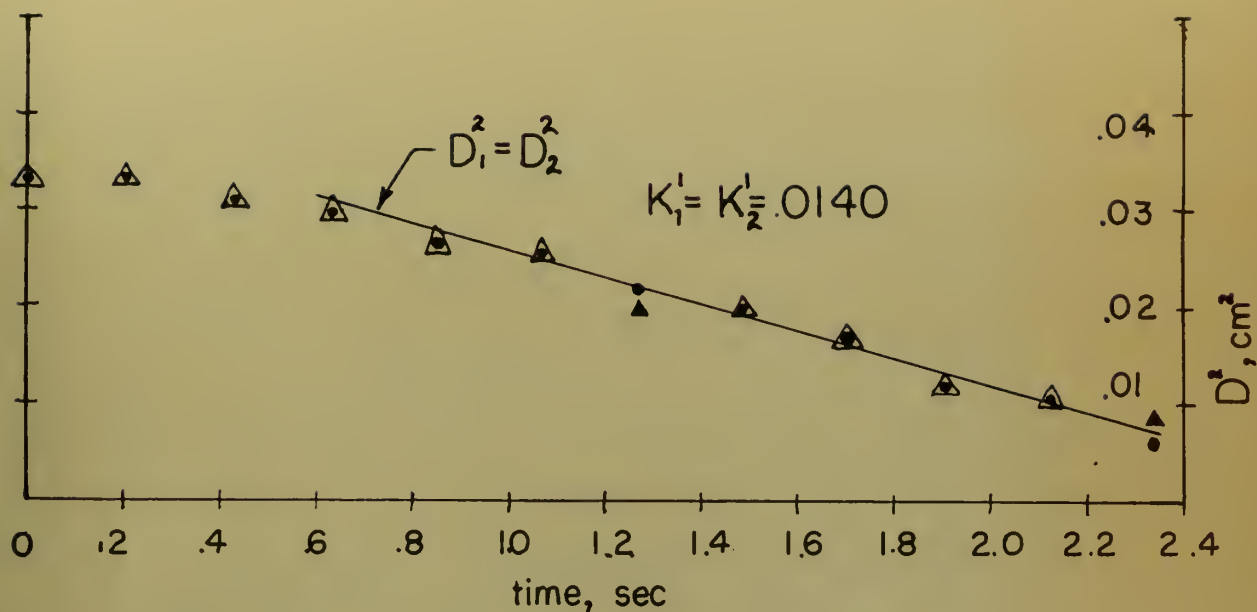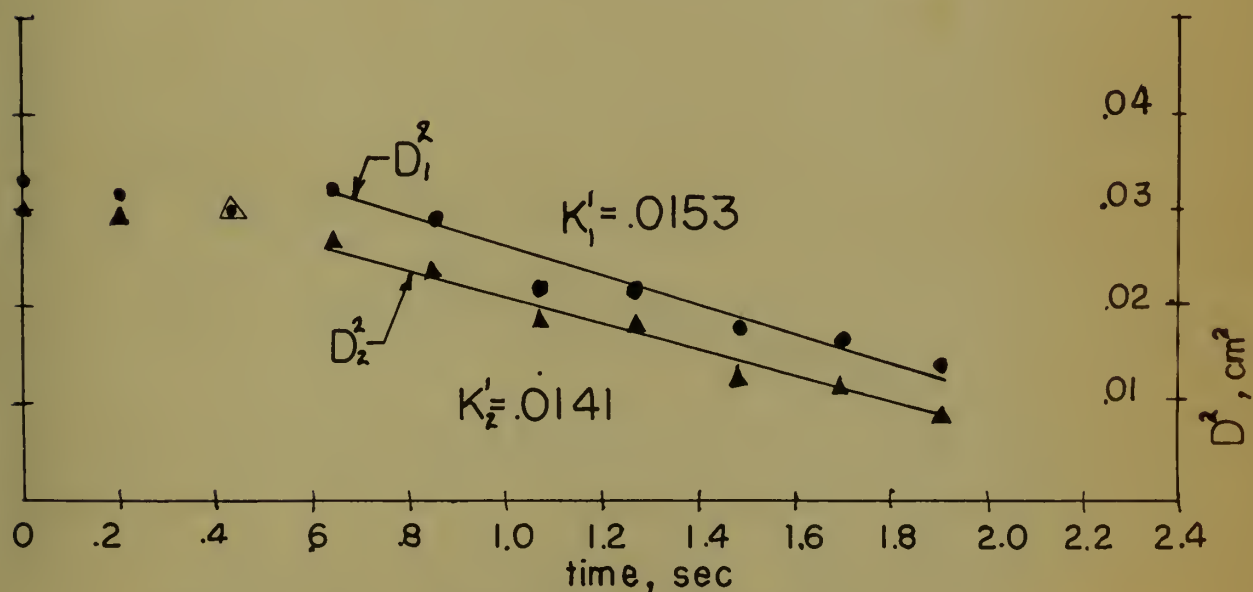
FIGURE 9. PLOTS OF D^2 vs time FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR FOR VARIOUS $C^°$
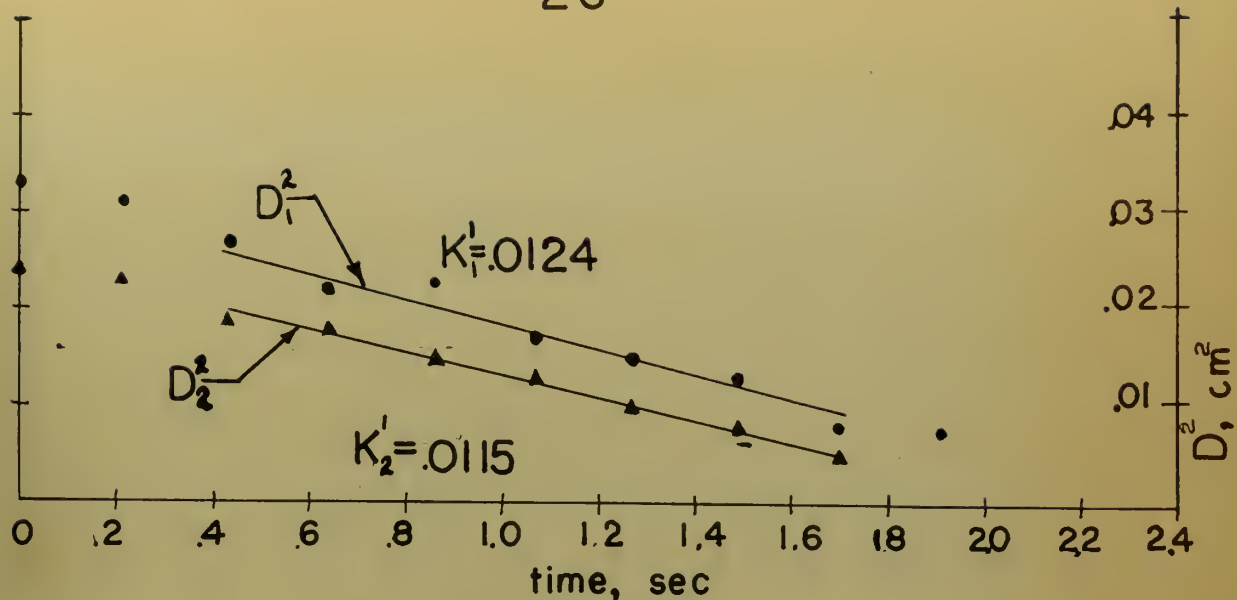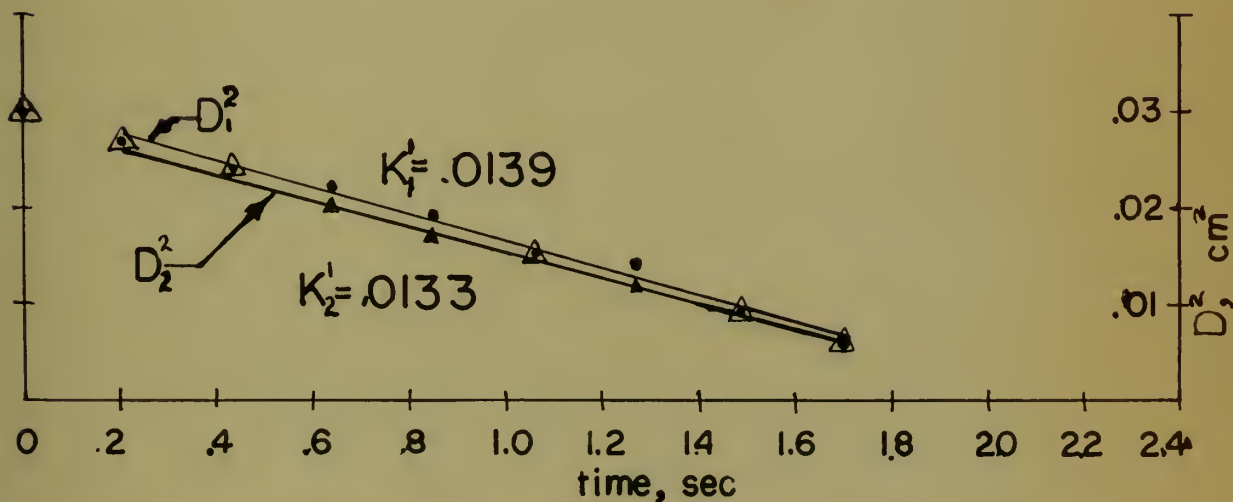
FIGURE 10. PLOTS OF D^2 vs time FOR TWO n -HEPTANE DROPLETS BURNING IN STILL AIR FOR VARIOUS C^o

(D_1^o =0.138cm, D_2^o =0.134cm, C^o =0.208cm)
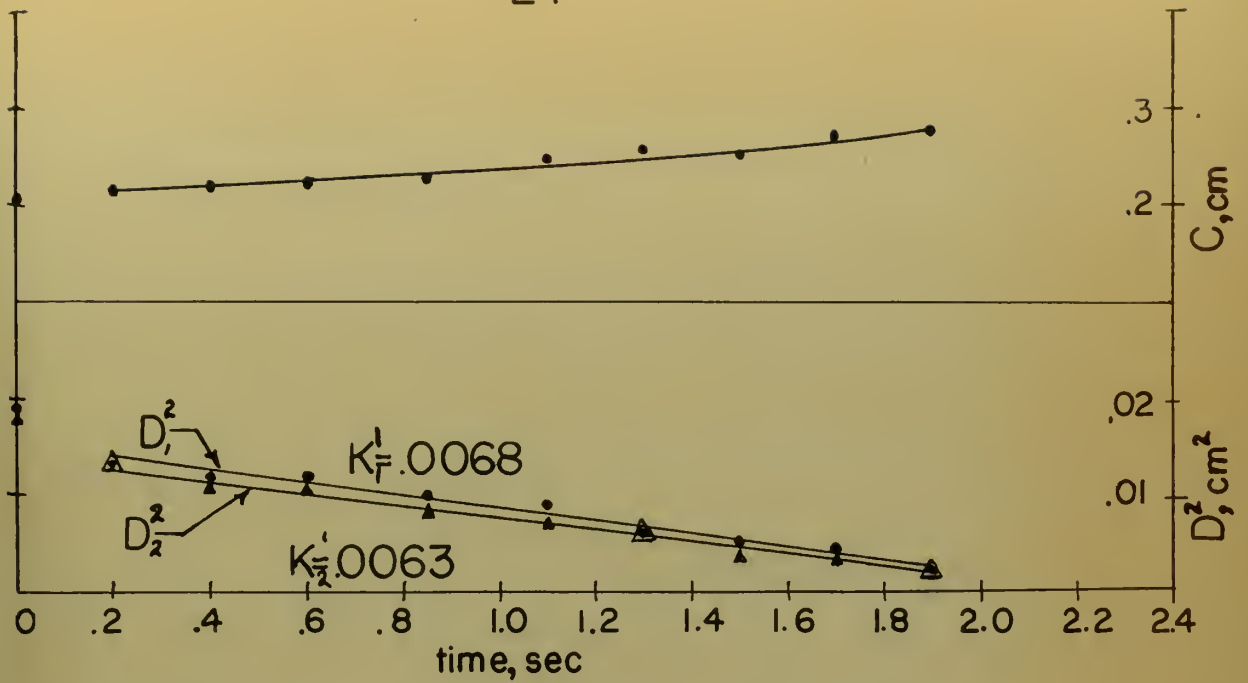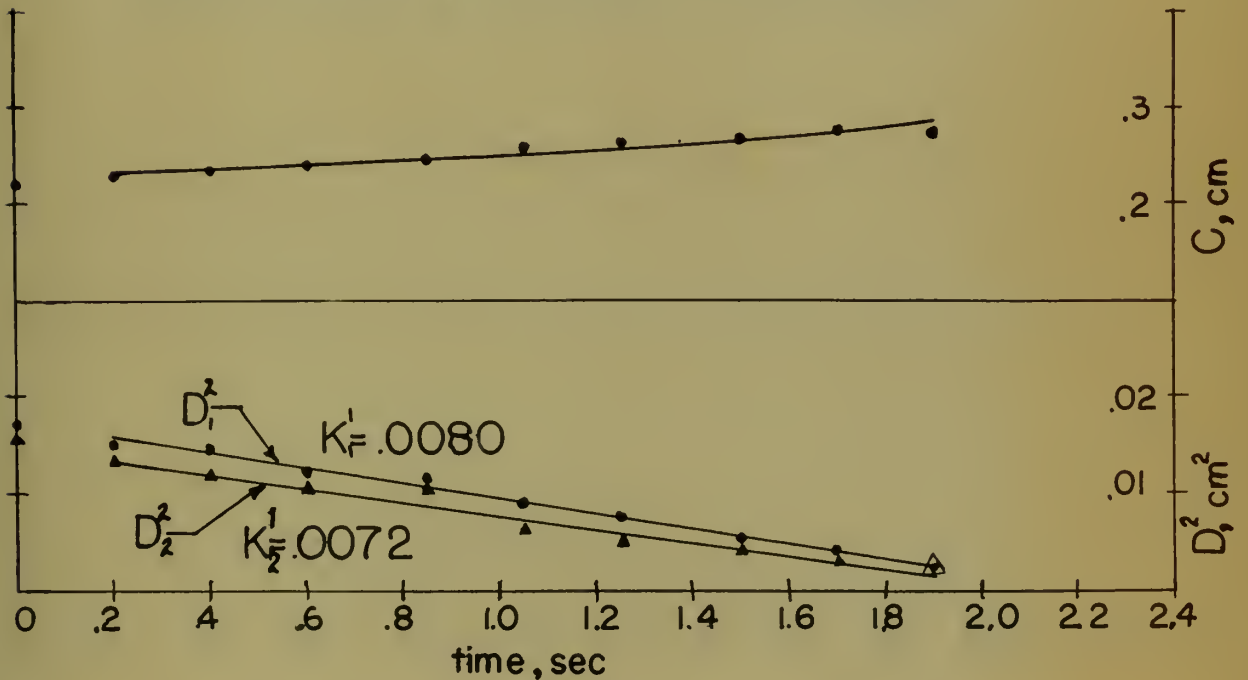
(D_1^o =0.130 cm, D_2^o =0.127cm, C^o =0.222cm)

FIGURE II. PLOTS OF D^2 vs time and C vs time FOR TWO
n -HEPTANE DROPLETS BURNING IN STILL AIR FOR
VARIOUS C^o
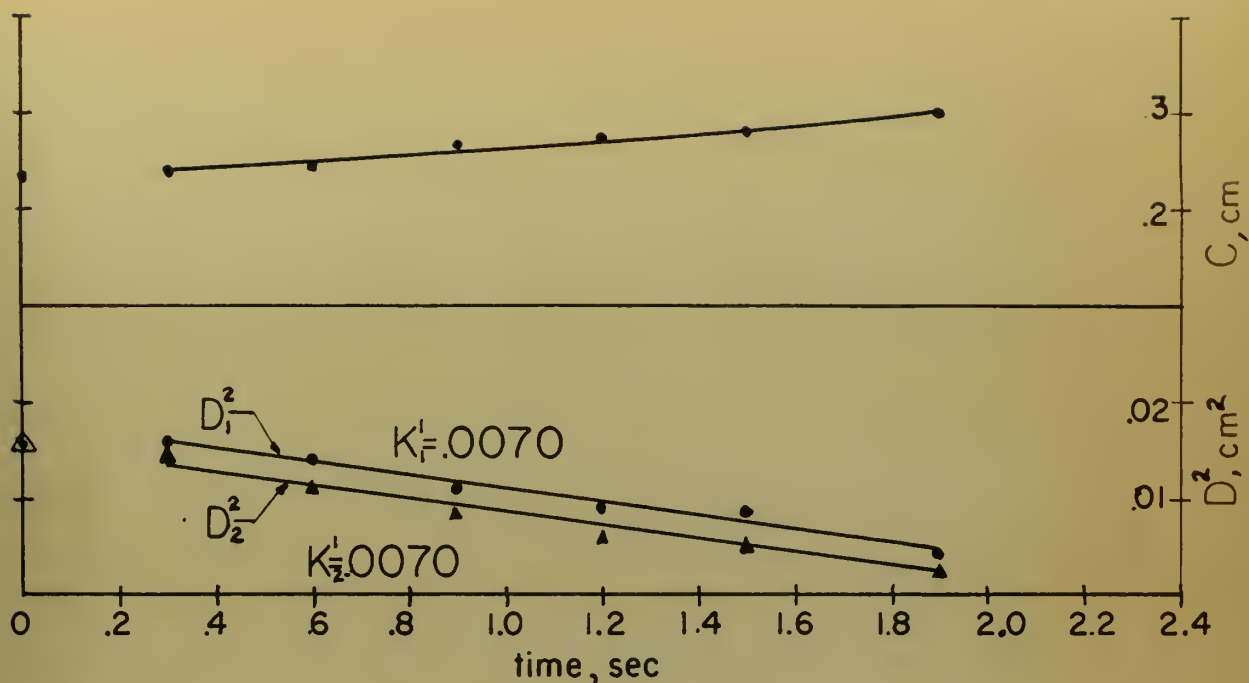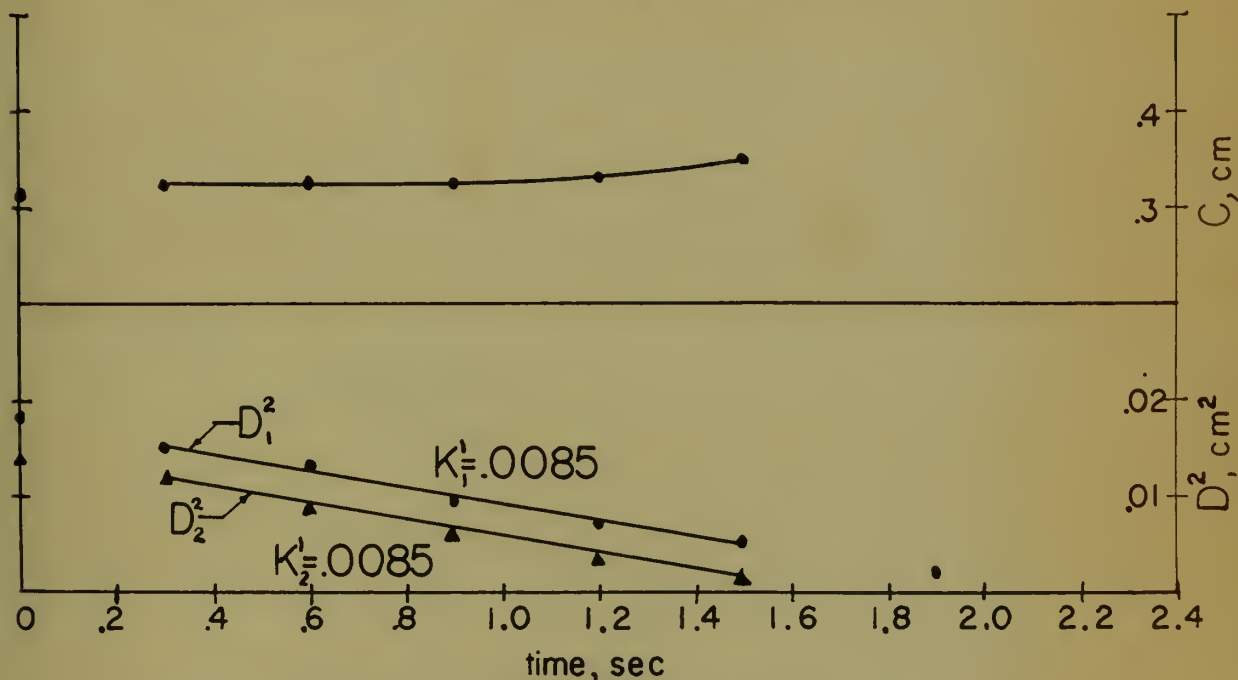
FIGURE 12.   PLOTS OF D^2 vs time and C vs time FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR FOR VARIOUS C^o
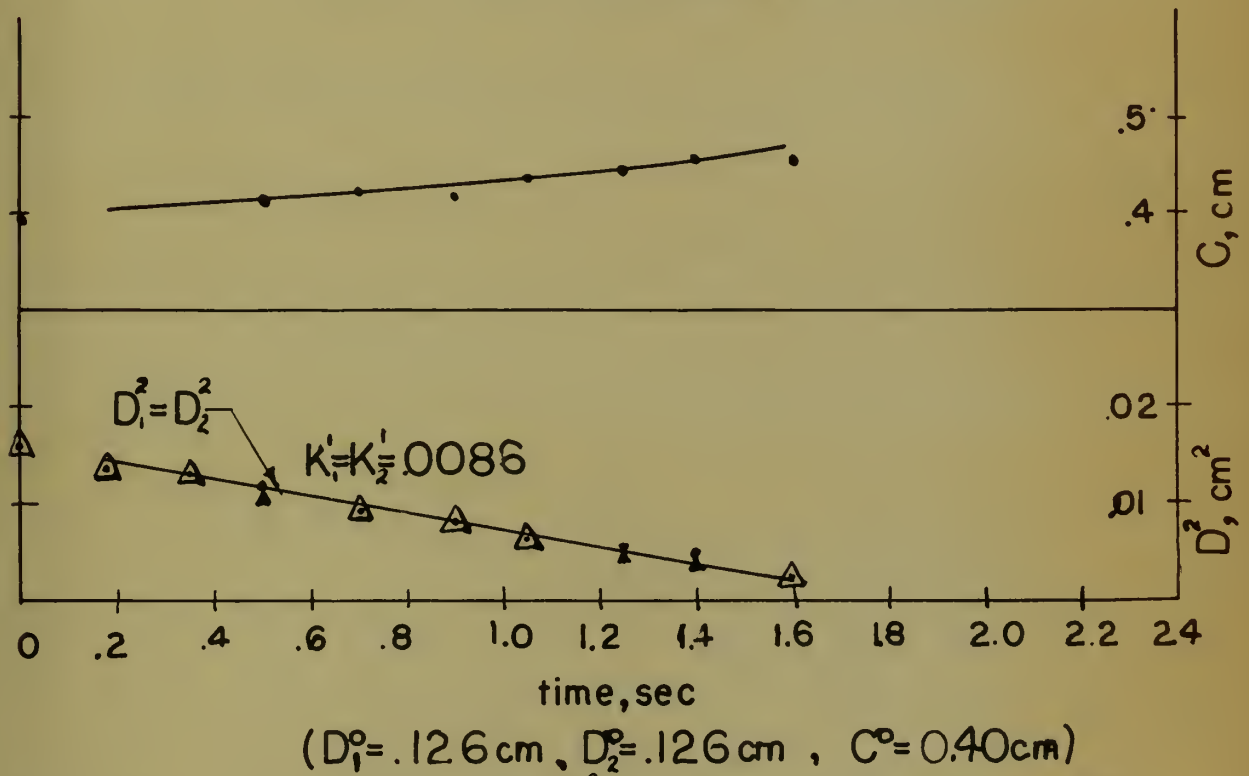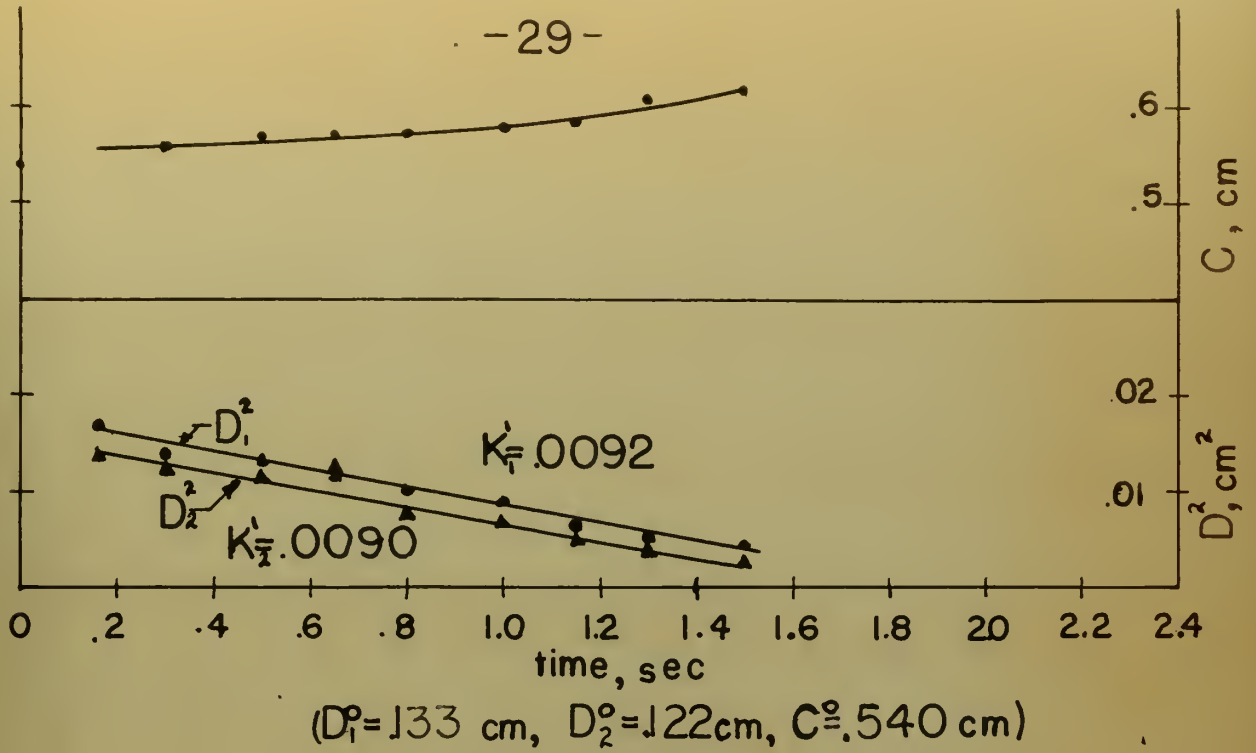
FIGURE 13. PLOTS OF D^2 vs time and C vs time FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR FOR VARIOUS C^o
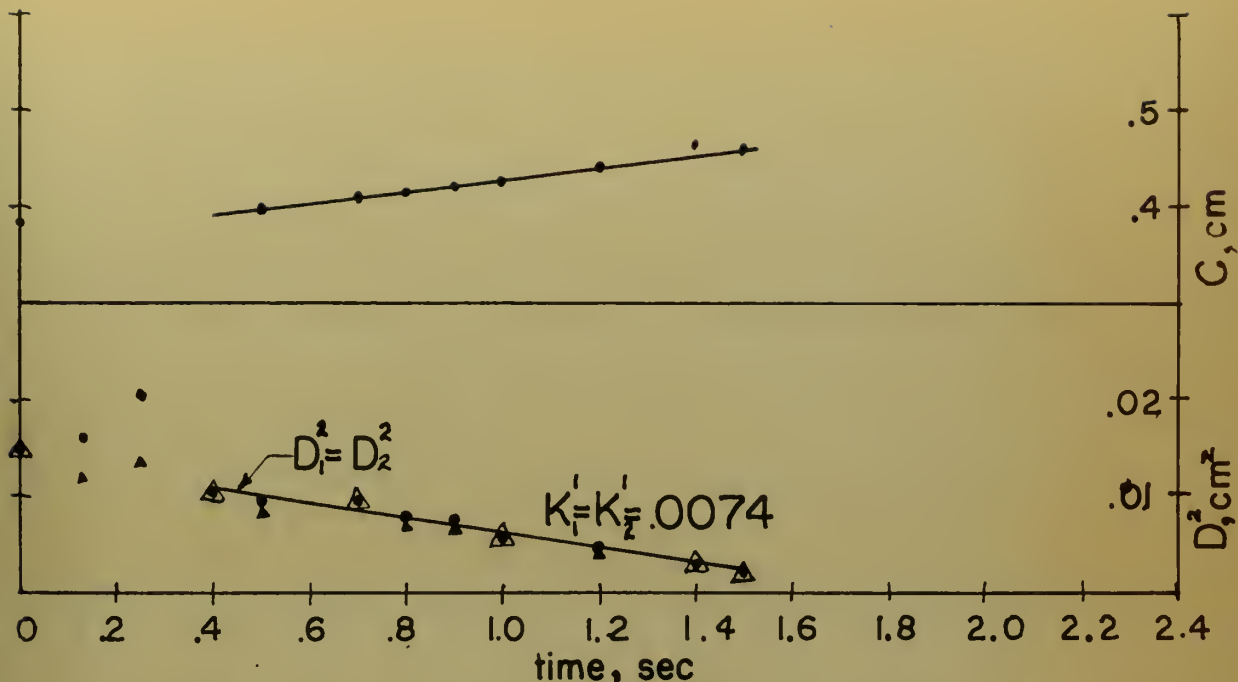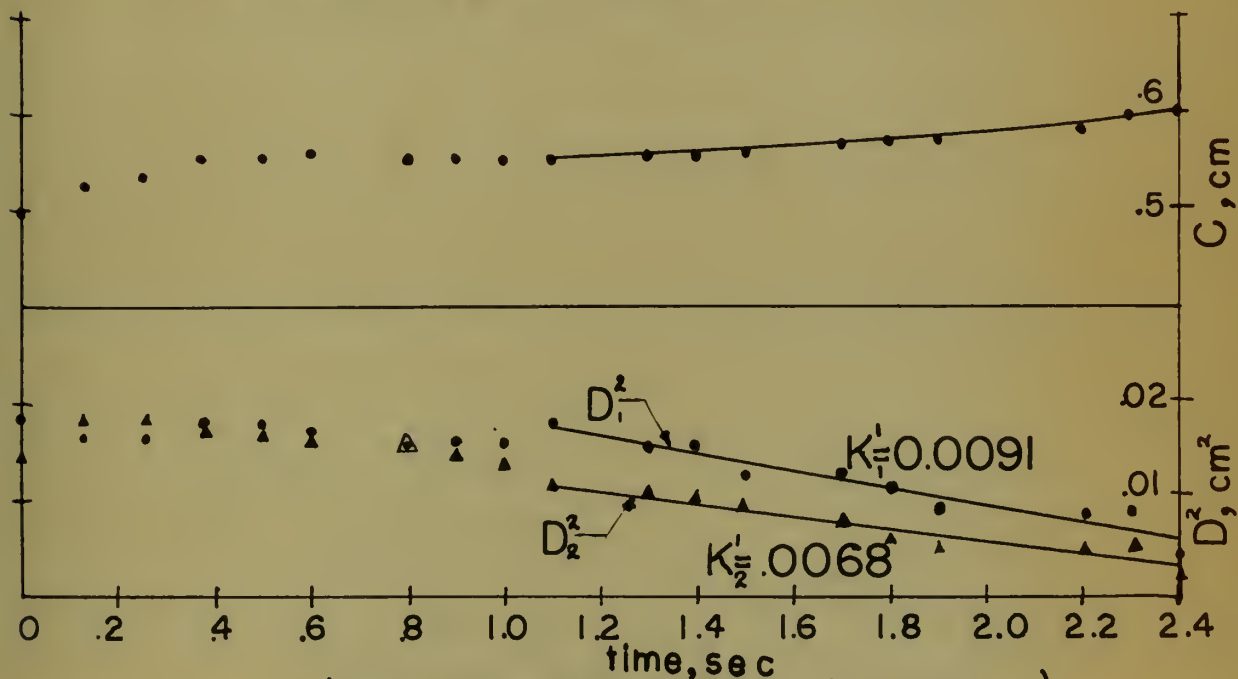
FIGURE 14. PLOTS OF D^2 vs time and C vs time FOR TWO
n-HEPTANE DROPLETS BURNING IN STILL AIR FOR
VARIOUS C^0
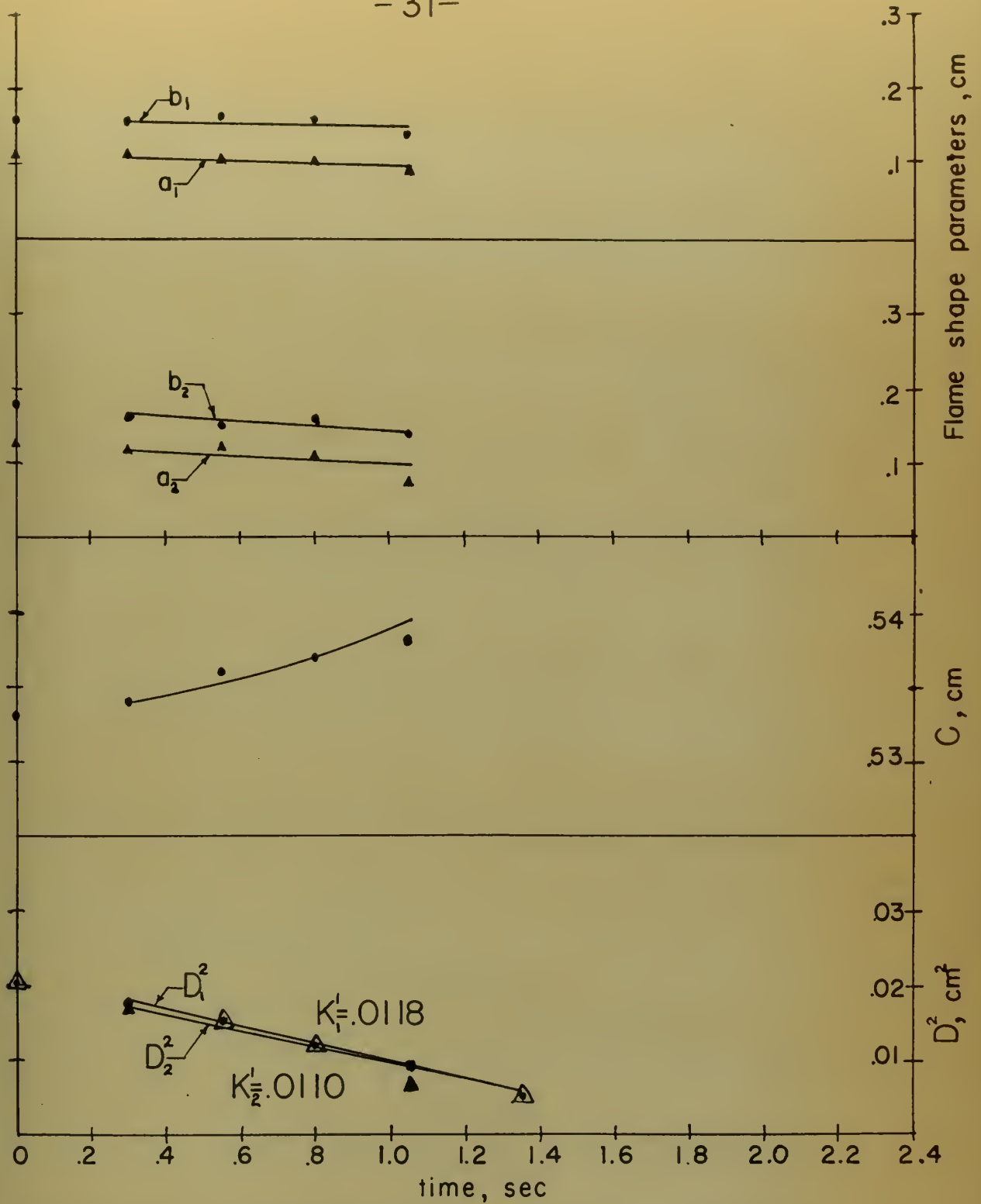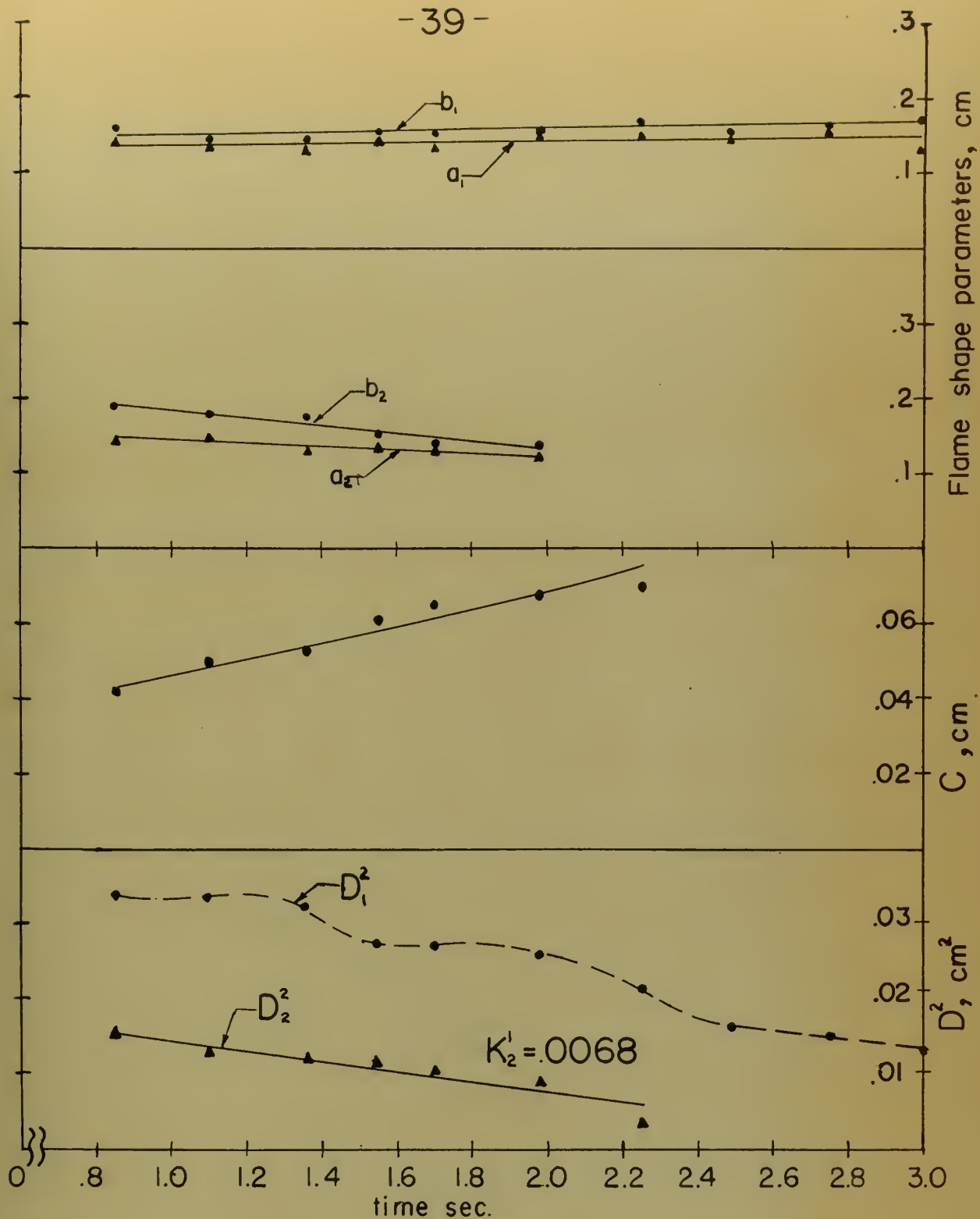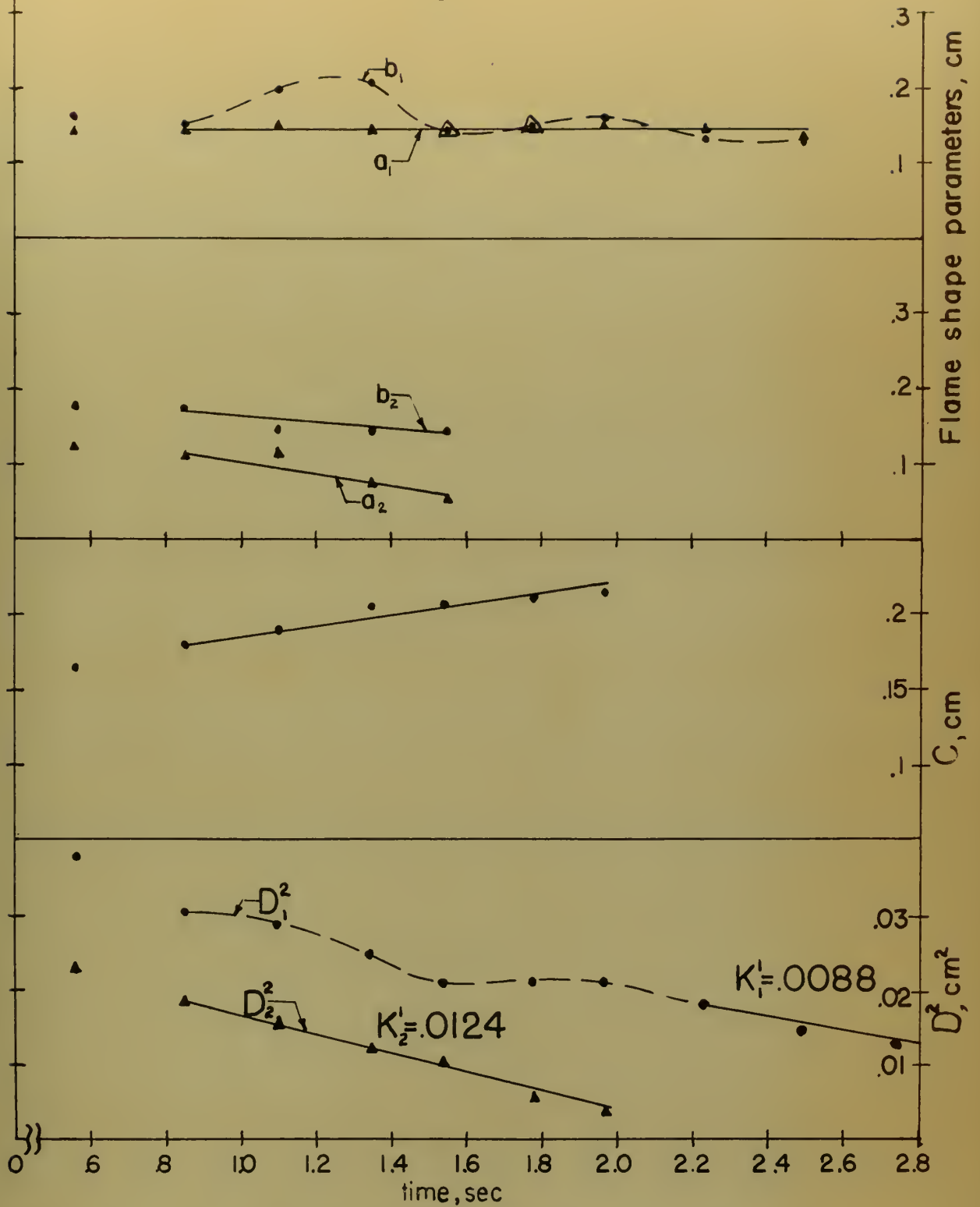
FIGURE 15. EXPERIMENTAL RESULTS FOR TWO n − HEPTANE DROPLETS BURNING IN STILL AIR (D_1^o=0.143 cm, D_2^o=0.142cm, C^o= 0.533 cm)
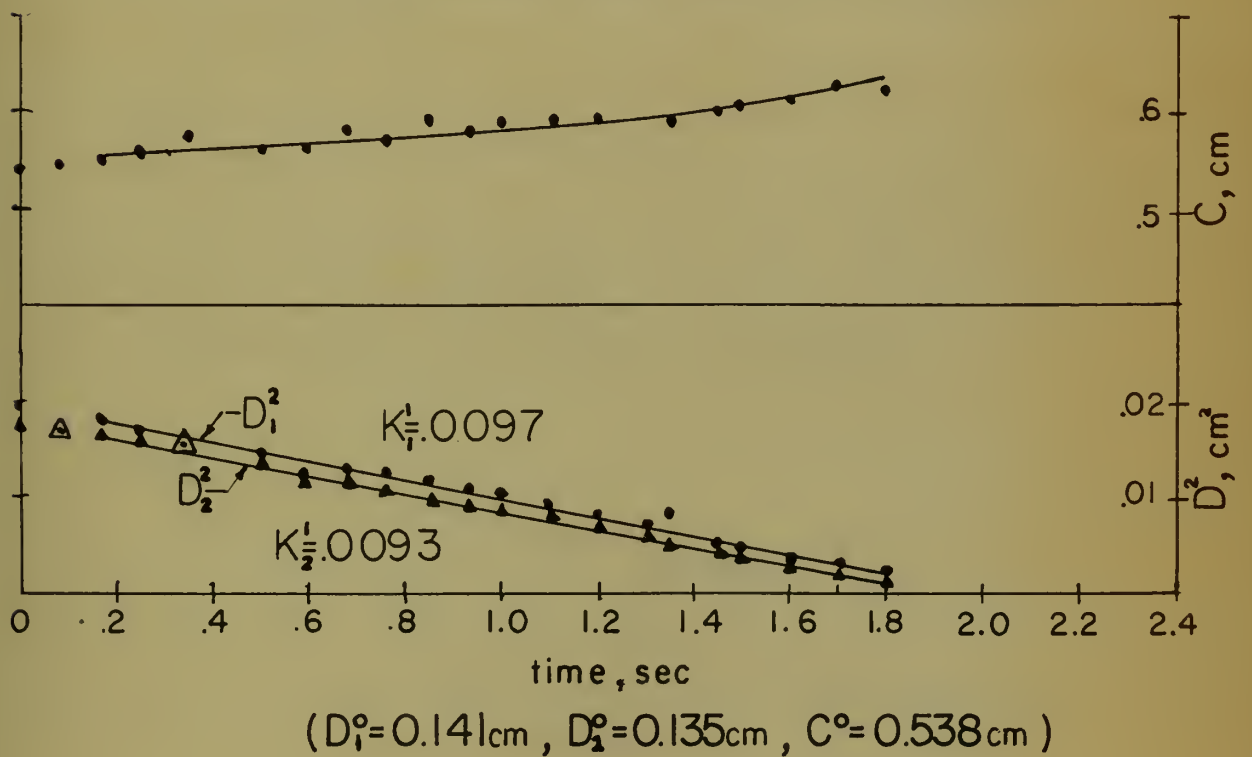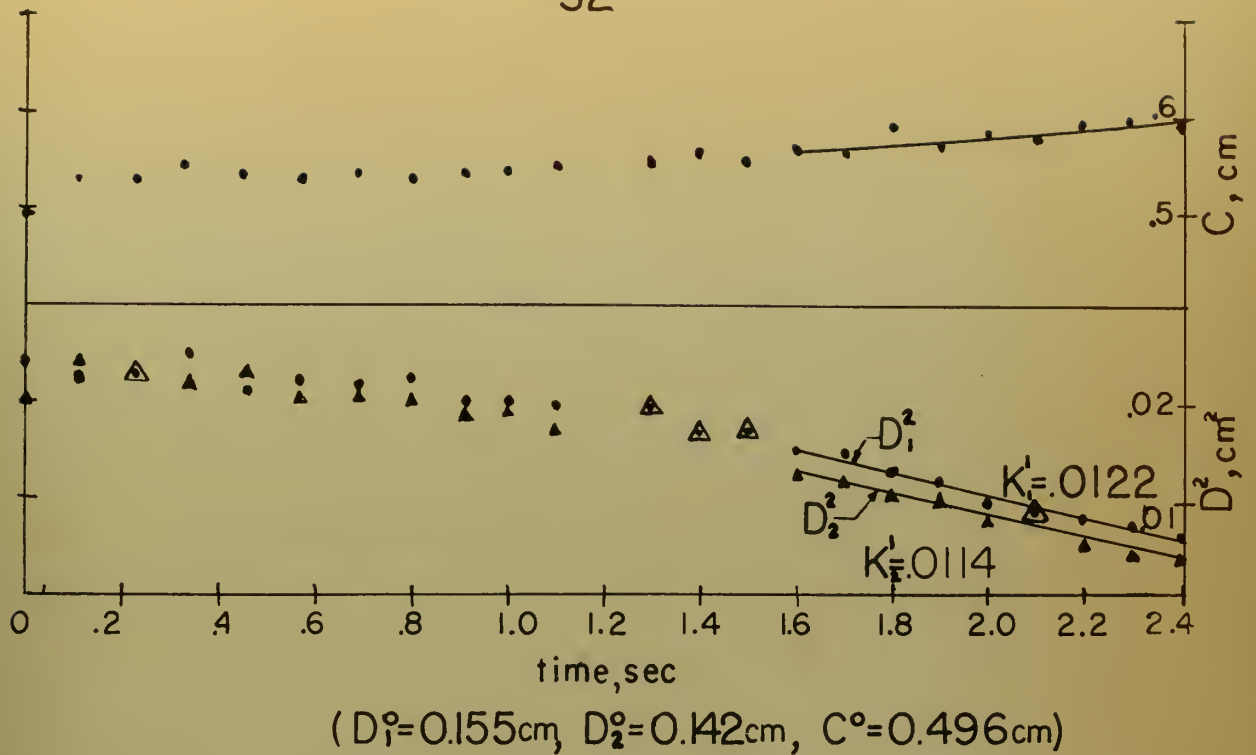
FIGURE 16.   PLOTS OF D^2 vs time and C vs time FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR FOR VARIOUS C^0
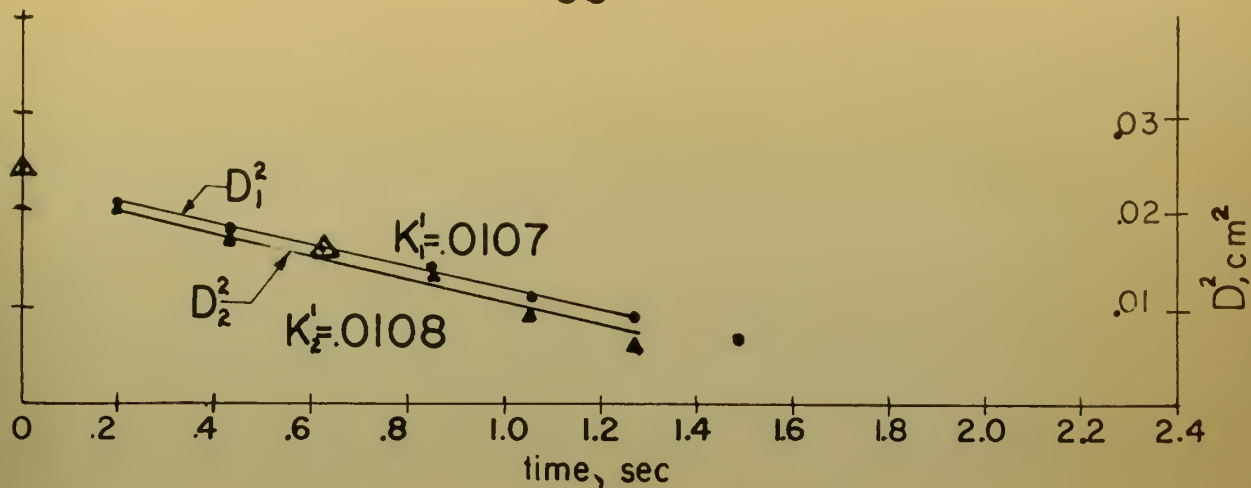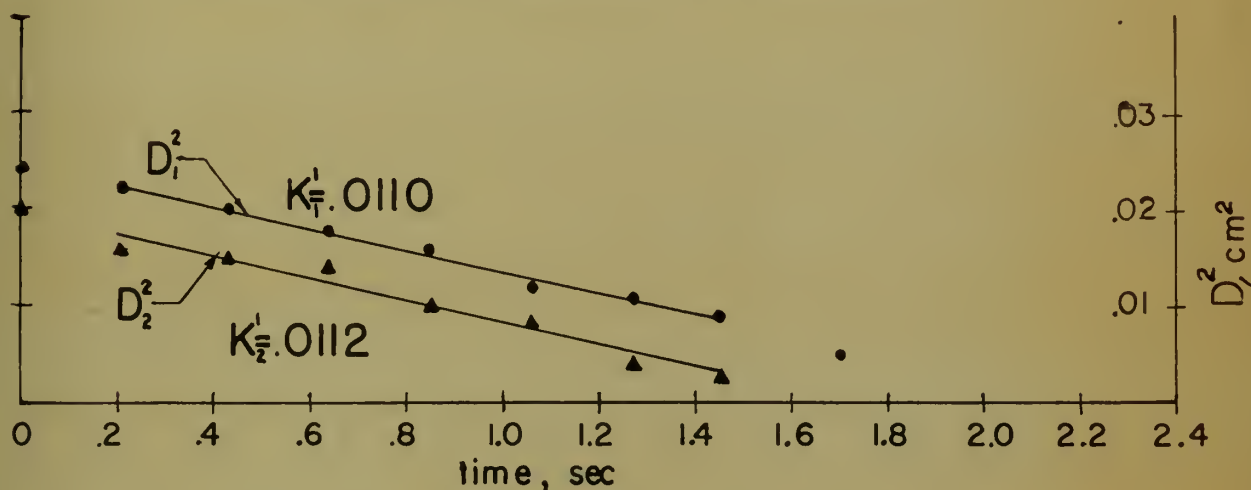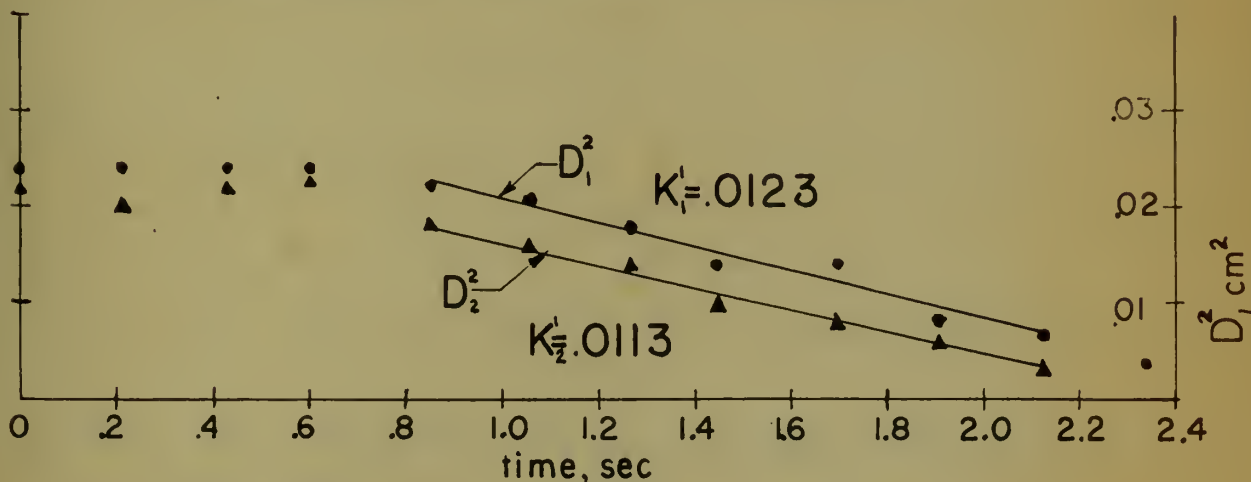
FIGURE 17. PLOTS OF D^2 vs time FOR TWO n-HEPTANE
DROPLETS BURNING IN STILL AIR FOR VARIOUS C^0

FIGURE 18. EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR (D_1^0=0.208 cm, D_2^0=0.155cm, C^0=0.126cm)
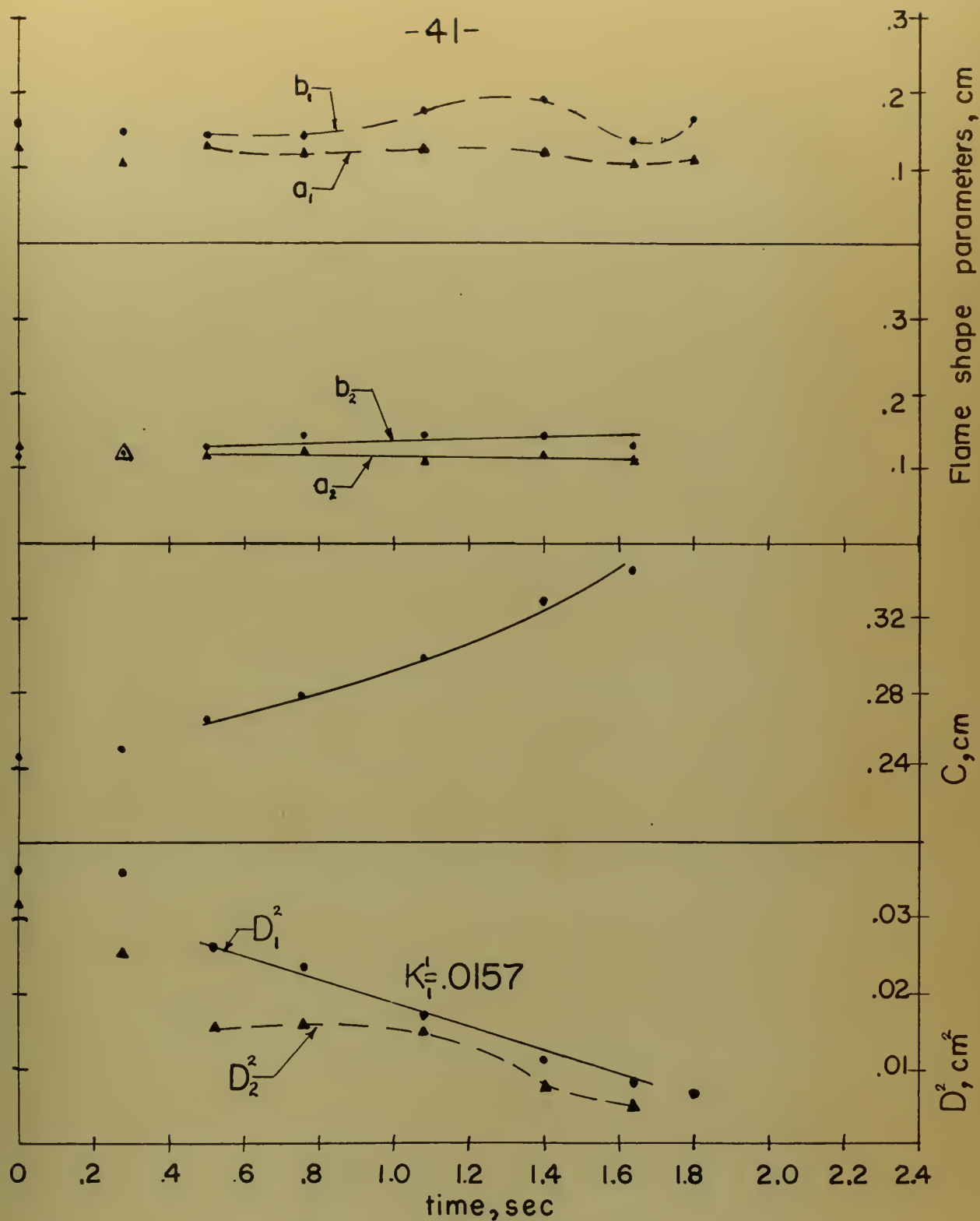
FIGURE 19. EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR (D_1^o=0.209 cm, D_2^o=0.170cm, C^o=0.352cm)
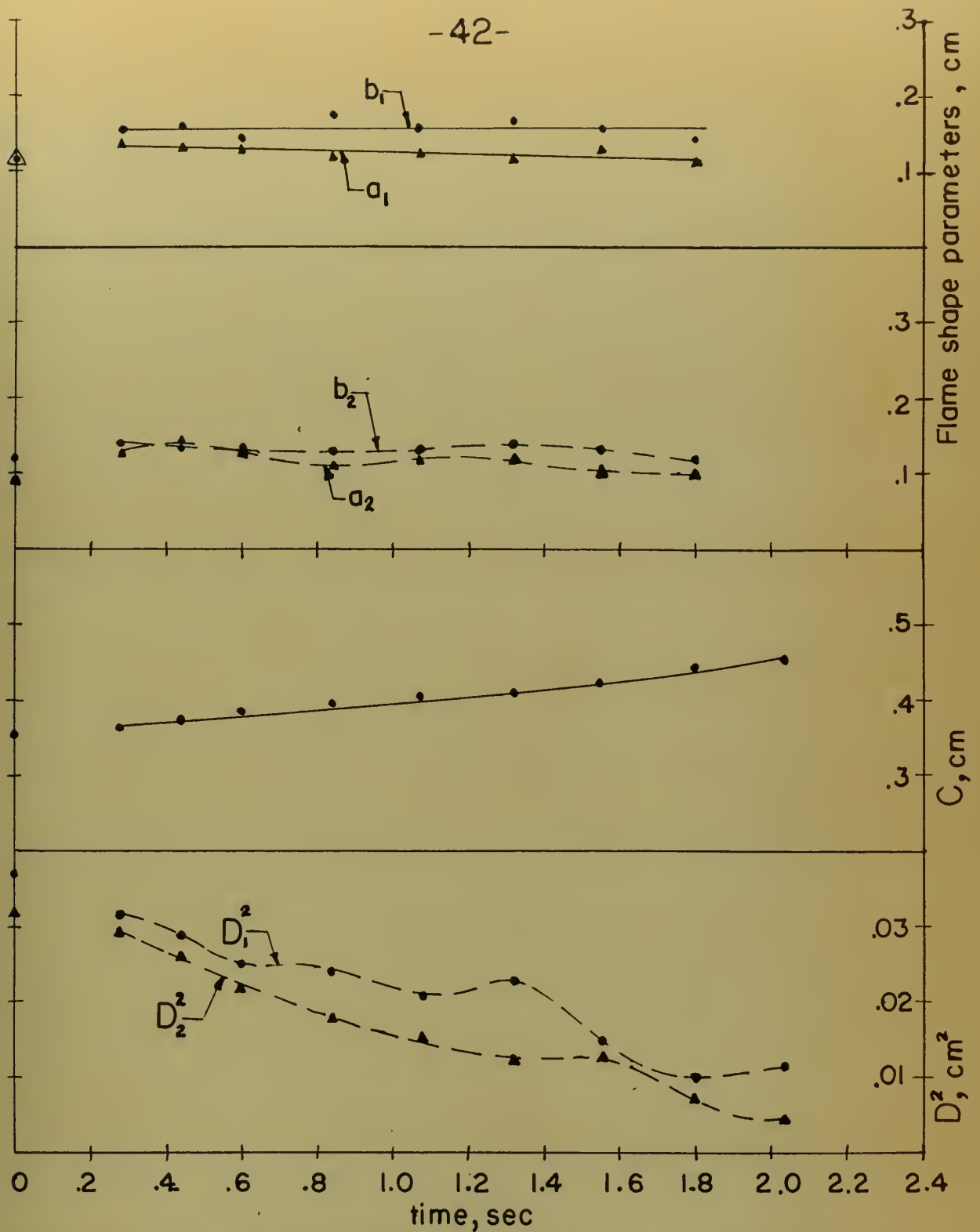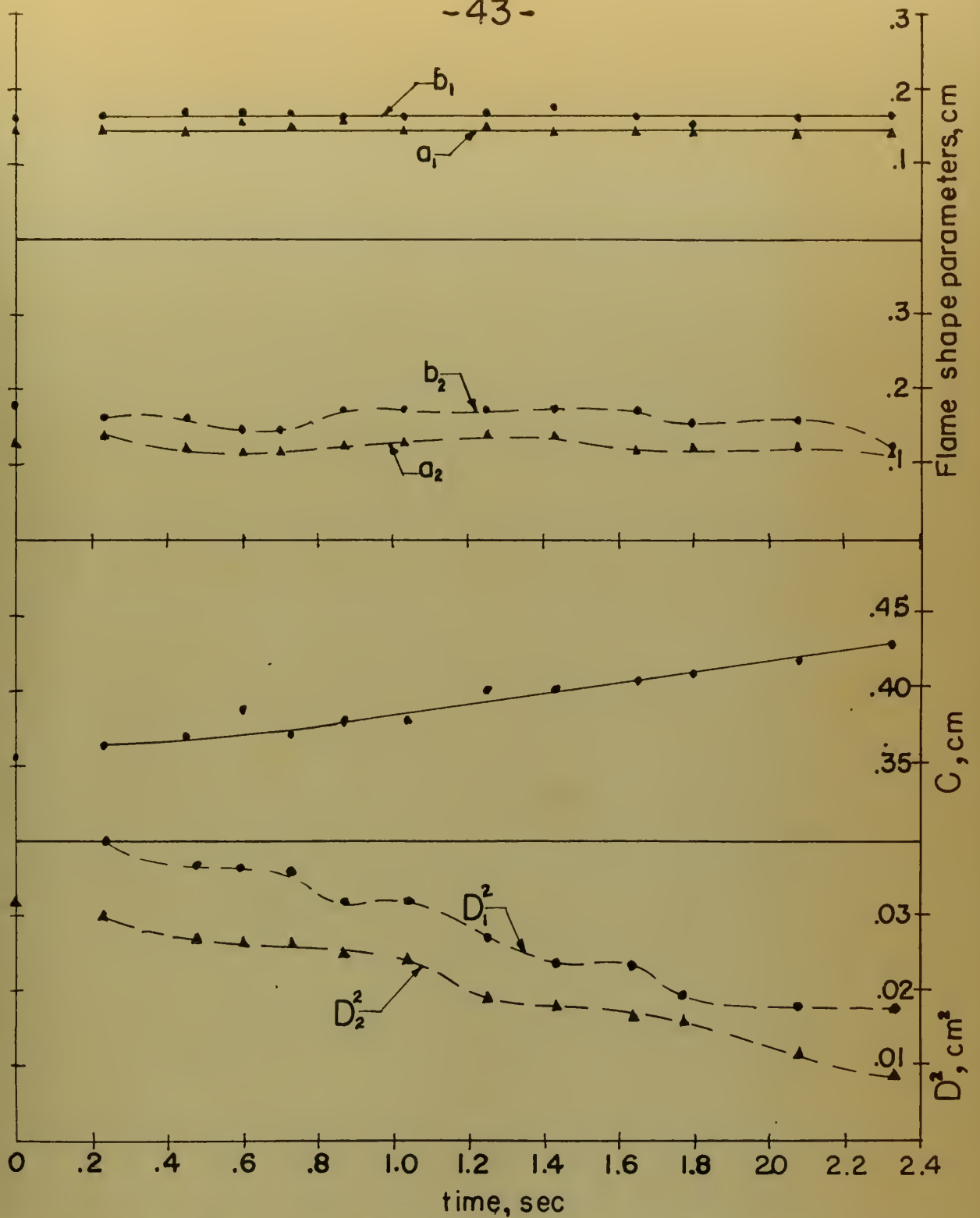
FIGURE 20.   EXPERIMENTAL RESULTS FOR TWO n -
HEPTANE DROPLETS BURNING IN STILL AIR (D_1^0=0.198
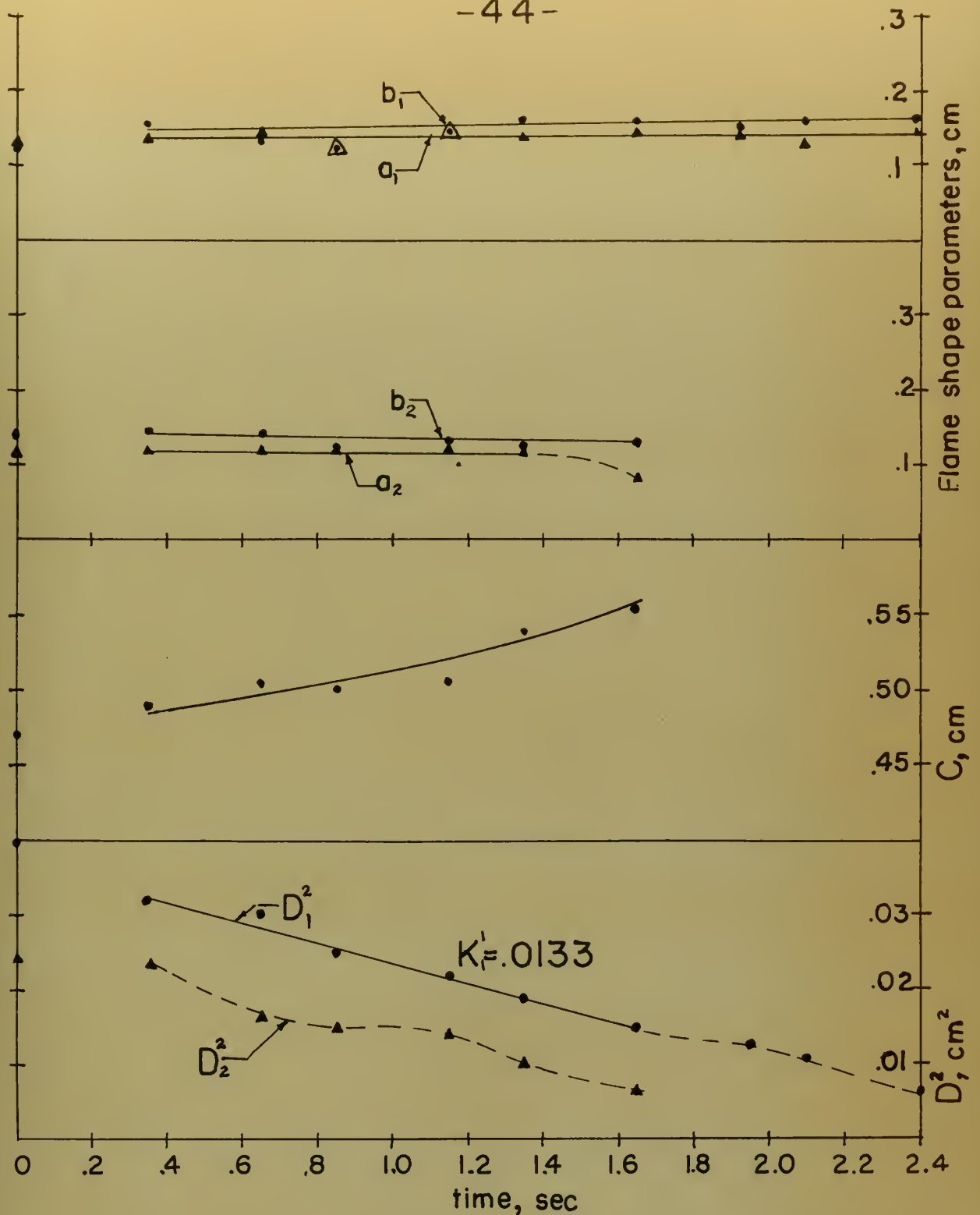cm, D_2^0=0.140cm, C^0=0.375cm)

FIGURE 21. EXPERMENTAL RESULTS FOR TWO n - HEPTANE DROPLETS BURNING IN STILL AIR (D_1^0= 0.167 cm, D_2^0= 0.115 cm, C^0 = 0.520 cm)
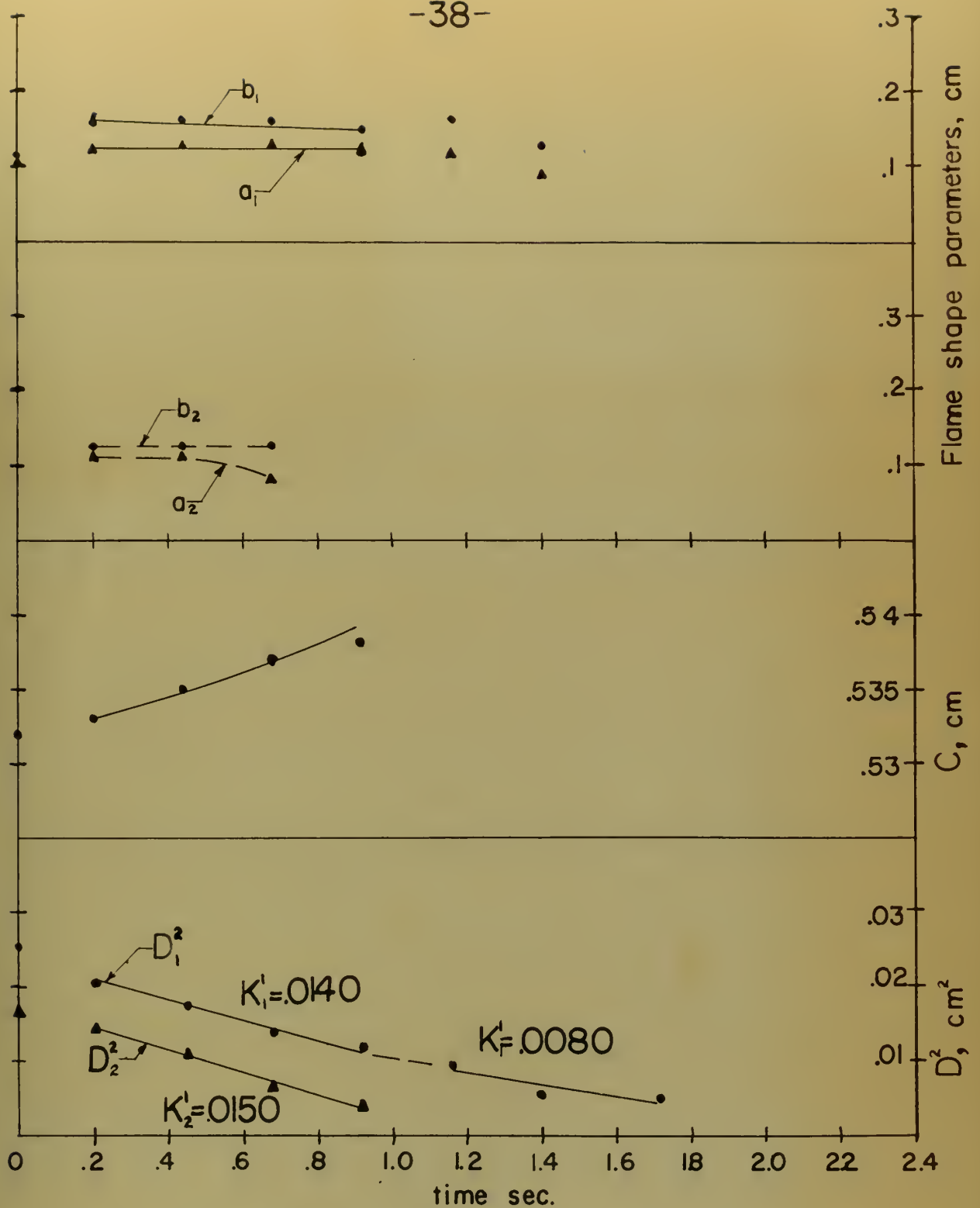
FIGURE 22. EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR (D_1^0=0.160 cm, D_2^0=0.131 cm, C^0=0.532 cm)

FIGURE 23. EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR (D_1^0=0.192 cm, D_2^0=0.148 cm, C^0=0.026 cm)

FIGURE 24. EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR (D_1^o = 0.208 cm, D_2^o = 0.164 cm, C^o = 0.150 cm)

FIGURE 25. EXPERIMENTAL RESULTS FOR TWO n - HEPTANE DROPLETS BURNING IN STILL AIR (D_1^o = 0.191 cm, D_2^o = 0.178 cm, C^o = 0246 cm)

FIGURE 26. EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR (D_1^o= 0.192 cm, D_2^o=0.180cm, C^o=0.355cm)

FIGURE 27. EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR ($D_1^o=0.202$ cm, $D_2^o=0.179$ cm, $C^o=0.362$ cm)

FIGURE 28. EXPERIMENTAL RESULTS FOR TWO n-HEPTANE DROPLETS BURNING IN STILL AIR (D_1^0=0.200 cm, D_2^0=0.156 cm, C^0=0.466 cm)
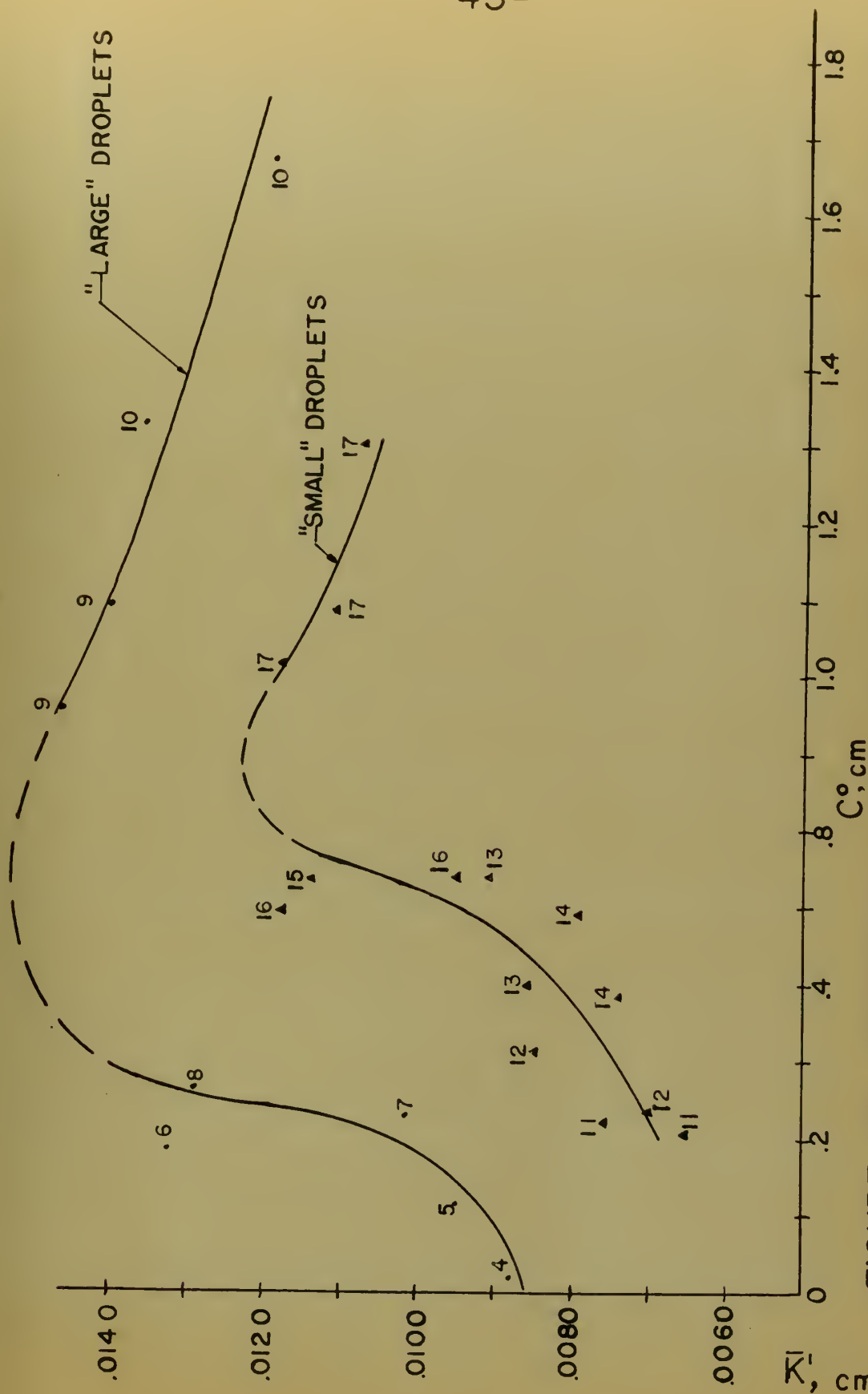
FIGURE 29. VARIATION OF THE AVERAGE EVAPORATION CONSTANT $\bar{K}'$ WITH $C°$ FOR DROPLET PAIRS WITH DIFFERENT INITIAL AVERAGE DIAMETERS $\bar{D}°$
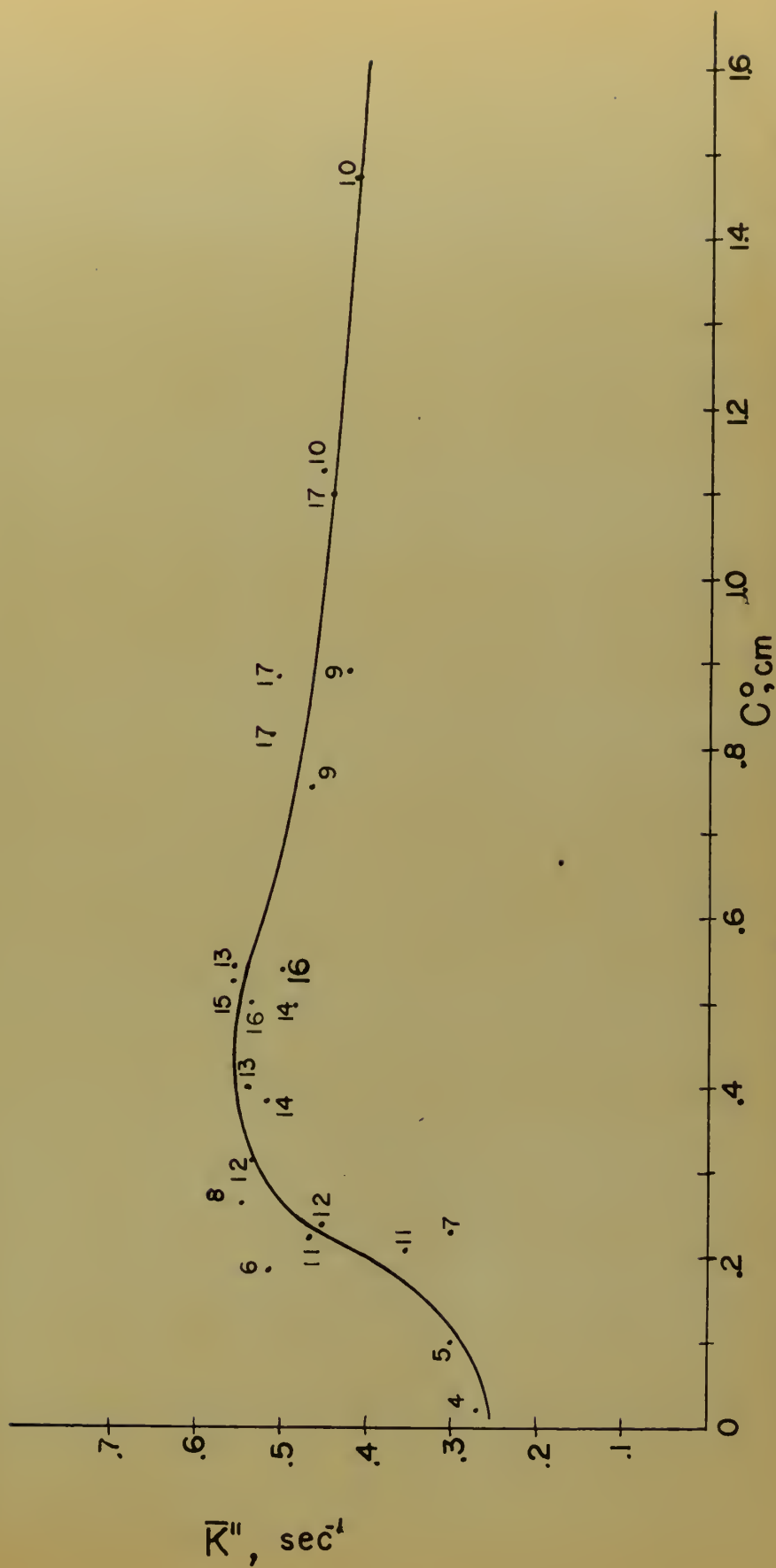
FIGURE 30. DEPENDENCE OF THE EVAPORATION FREQUENCY $\overline{K}''$ ON $C°$
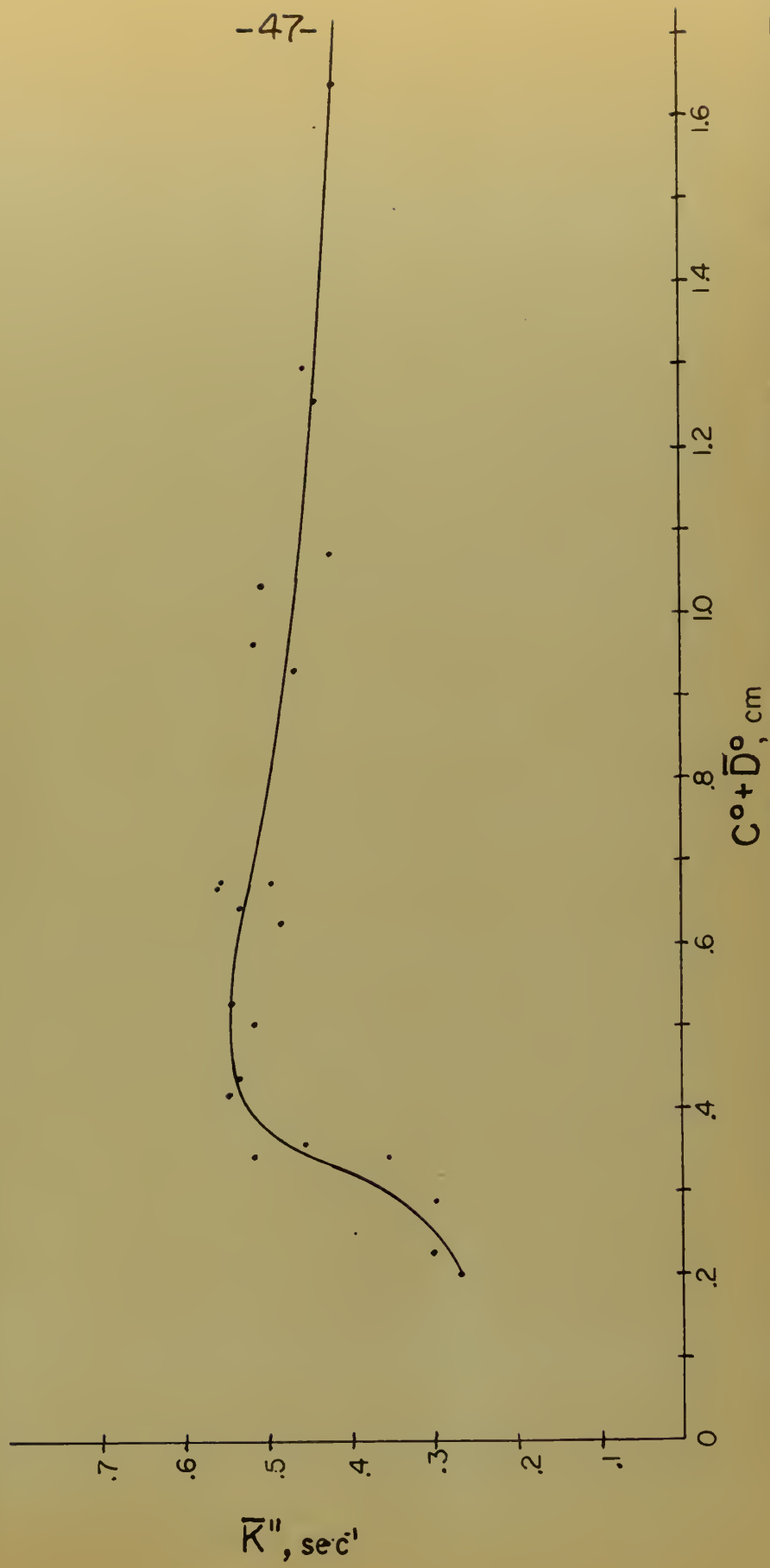
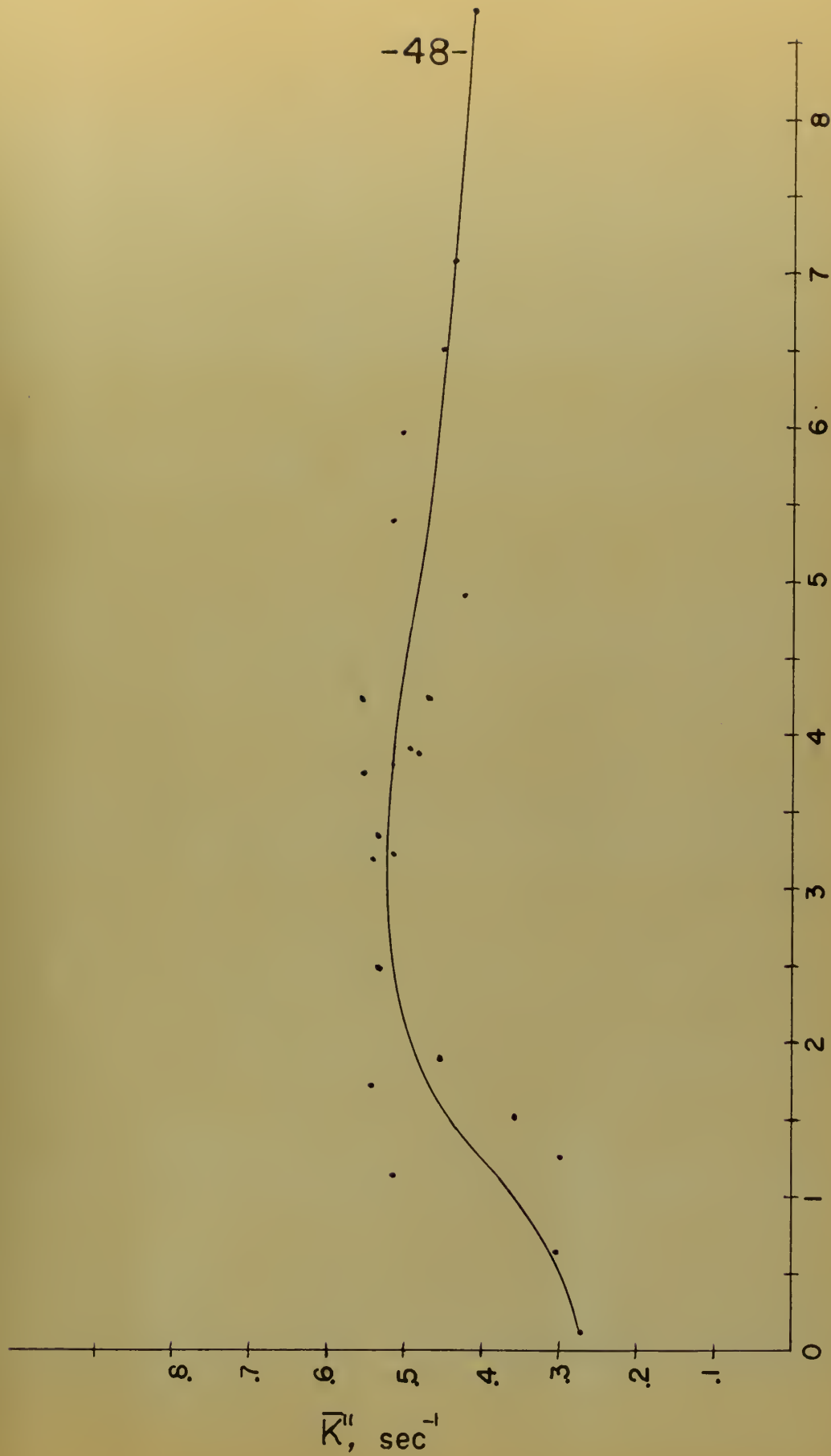FIGURE 31. DEPENDENCE OF THE EVAPORATION FREQUENCY $\bar{K}''$ ON $C^o + \bar{D}^o$

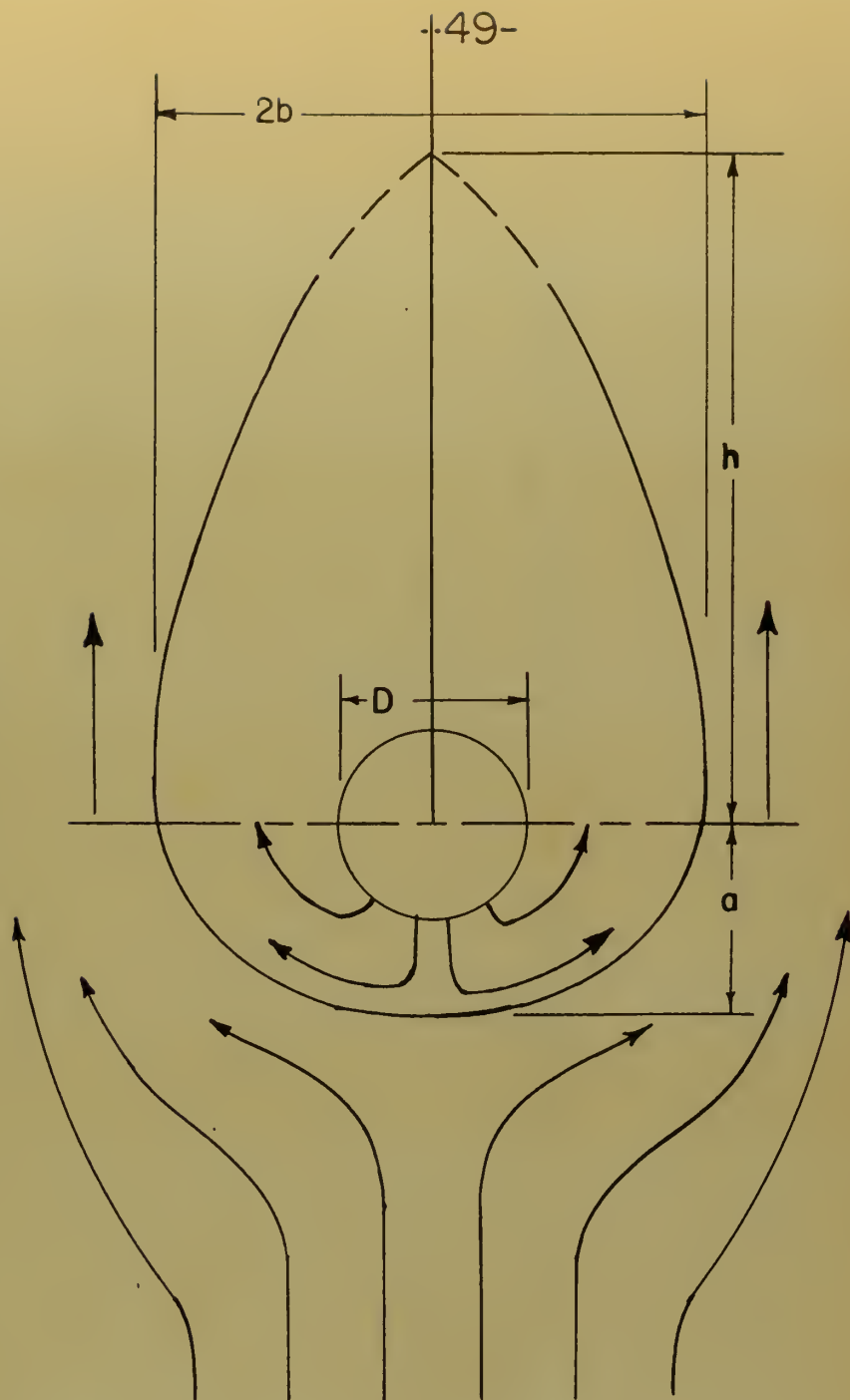FIGURE 32.   DEPENDENCE OF THE EVAPORATION FREQUENCY $\bar{K}''$ ON $C°/\bar{D}°$

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FIGURE 33. SCHEMATIC DIAGRAM OF BURNING
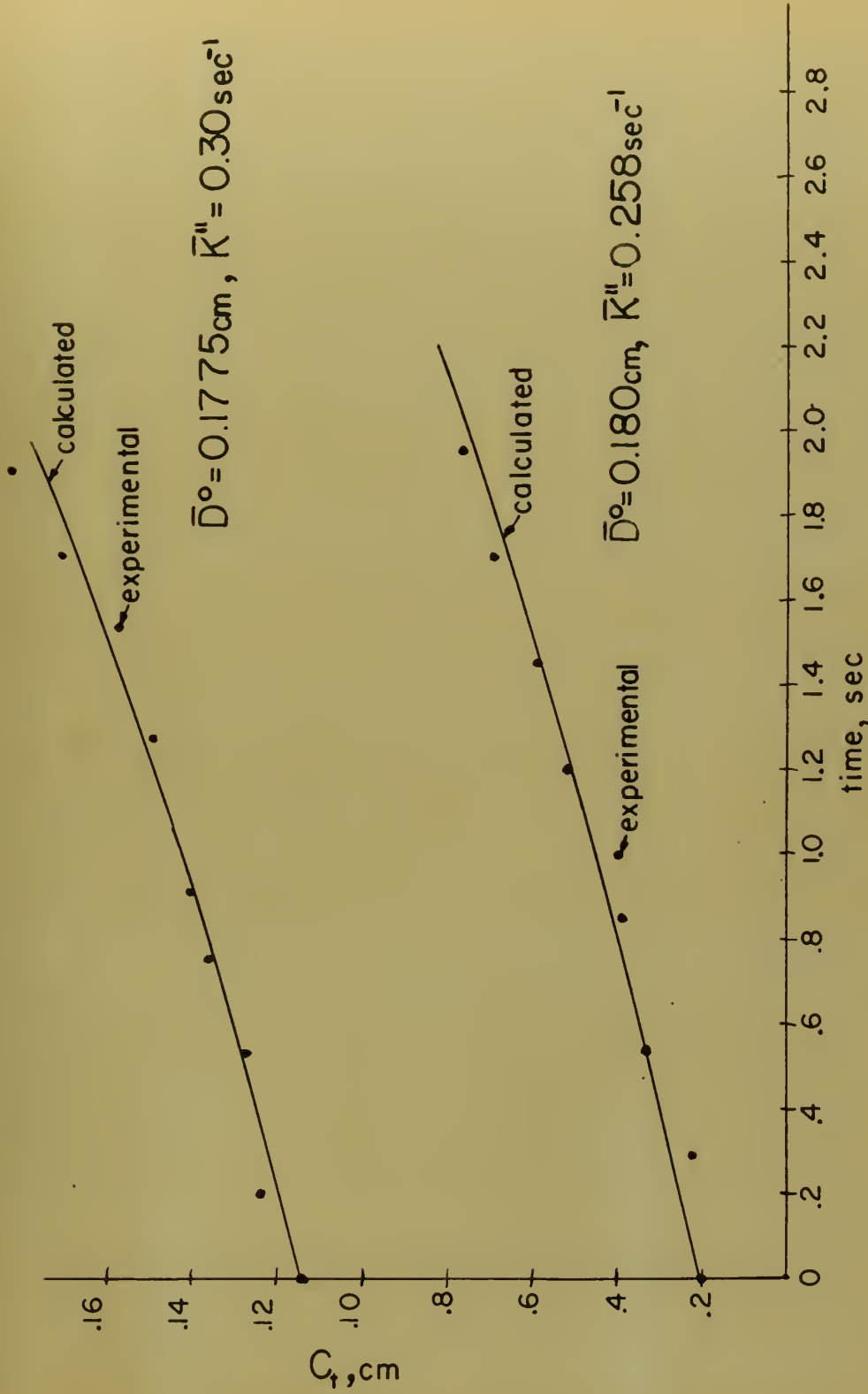FUEL DROPLET. STREAMLINES IDENTIFIED
BY ARROWS.

FIGURE 34. PLOT OF EXPERIMENTAL AND CALCULATED VALUES
FOR C_t vs time WHERE $C_t = C^o + \bar{D}^o(1 - \sqrt{\bar{K}'' t})$